United States v. Princeton Gamma-Tech, Inc., Fifth Dimension, Inc., S&S Investment,
George Sands, Jr., and Jeffrey Sands
No. CV-91-809 (AET)
United States District Court, District of New Jersey

REBUTTAL REPORT

MONTGOMERY TOWNSHIP HOUSING DEVELOPMENT SUPERFUND SITE
and
ROCKY HILL MUNICIPAL WELL SUPERFUND SITE
SOMERSET COUNTY, NEW JERSEY

prepared for the
U.S. Department of Justice
Environmental Enforcement Section
Washington, DC

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1. INTRODUCTION

This rebuttal report responds to reports by Richard G. Shepherd of Conestoga-Rovers & Associates (CRA) prepared on behalf of defendant Princeton Gamma-Tech, Inc. (PGT) in United States v. Princeton Gamma-Tech, Inc., Fifth Dimension, Inc., S&S Investment, George Sands, Jr., and Jeffrey Sands. The current report has been prepared by Gary R. Chirlin on behalf of plaintiff United States. This report consists of this introduction (Section 1) and two additional sections. Section 2 addresses Shepherd's[1] opinions, as presented in CRA (March 2000, volume 1) *Assessment of Princeton Gamma-Tech as a Potential Source at the MTHD and RHMW Superfund Sites,* concerning environmental data collected at PGT (disposal history, soil data, soil gas data, shallow ground-water data) and their implications for PGT as a source of ground-water contamination. Section 3 of the current report addresses Shepherd's opinions, as presented in CRA (March 2000, volume 2) *Assessment of Sources and Pathways of Groundwater Contamination at the MTHD and RHMW Superfund Sites,* concerning other potential sources of TCE contamination at the Sites and the migration of ground water and TCE within the Sites. Findings from the recent field study at Princeton Chemical Research, CRA (May 2000), also are addressed in Section 3.

The expert reports for defendants and third party plaintiffs Fifth Dimension, Inc. (FDI) and Hilton Reality, et al. agree that trichloroethene (TCE) was released at FDI and that some of that TCE migrated to Rocky Hill municipal well (RHMW) (Environ, March 2000, pp. 5, 16-18). Therefore the present rebuttal report does not discuss FDI contamination at RHMW.

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[1] Throughout this report "Shepherd" refers to the contents of CRA (March 2000, vols. 1, 2).

2. PGT AS A SOURCE OF TCE

Shepherd concludes that "based on extensive environmental and hydrogeologic data, it is clear that the source of TCE in the groundwater beneath the PGT property originated at other locations" and that "historical operations at PGT are not a source of TCE that subsequently contaminated groundwater" {pg. 45}. Shepherd accepts that "releases of TCE took place on the PGT property (on the surface, shallow soils and in the septic systems)" {pg. 45}[2]. Shepherd also agrees that the shallow ground water beneath PGT is contaminated with TCE {vol. 1 Sect. 3.2.1; vol. 2 Figs. 3.8, 3.9}. However, for reasons which this report shows to be flawed, Shepherd does not believe that the releases at PGT reached the ground water beneath the property:

> "soil and soil gas samples...do not evidence a source of TCE on the PGT property" {pg. i};
> "the...environmental data collected on the PGT property...show no TCE in subsurface soils consistent with...a release...that has impacted groundwater flowing toward the MTHD area or the RHMW public well" {pg. i};
> "historical operations at PGT are not a source of TCE that subsequently contaminated groundwater" {pg. ii};
> "There is no evidence linking the minimal TCE use at PGT with underlying groundwater contamination" {p. 9};
> "investigations at...the northeast...and...southwest corners...of the PGT property found no source of TCE in subsurface soils located above the groundwater which would have to exist if a release to groundwater had occurred at the PGT property" {pg. i};
> "the alleged potential source areas of TCE releases on the PGT property (e.g., septic tanks, leach fields, a dirt pile, and transformer rocks) are all located in the northeast corner of the PGT property, while the highest TCE groundwater concentrations are located over 250 feet away in the southwest corner of the property" {pg. i};
> "the source of TCE in the groundwater beneath the PGT property originated at other locations" {pg. 27}
> "...the information, data presentations, and quantitative evidence presented in this CRA report [CRA March 2000, vol. 1] provide inviolable evidence that PGT is not the source of TCE underlying its property or at the Sites" {pp. 45-46}.

Shepherd has two bases for concluding that PGT's releases of TCE did not reach groundwater. The first basis is his interpreted lack of "linkage" or "connection" between the surface and ground water at PGT {pg. 45}. He assesses TCE concentration data for soil, soil gas, and ground water at PGT and concludes that no linkage is evidenced. Instead, Shepherd attributes observed TCE contamination in ground water at PGT to releases at other facilities and contaminant migration to PGT, and attributes observed soil gas TCE contamination at PGT to offgassing (volatilization) from the ground water.

In this report I respond to these Shepherd opinions by presenting a conceptual description of DNAPL behavior (Section 2.1) and examining the implications of PGT environmental sampling data from the soils and septic leachate (Section 2.2), soil gas (Section 2.3) and ground water (Section 2.4).

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[2] I use { } brackets to refer to pages, tables, or figures in CRA (2000, vol. 1). I indicate CRA (2000, vol. 2) by {vol. 2, ...} and CRA (May 2000) by {May 2000, ...}.

Shepherd's second basis for concluding that PGT's releases did not reach ground water is his analysis of the fate of the spilled TCE product at PGT. He develops an estimate of the quantity of TCE product released to the surface at PGT and a model of the fate and transport of the spilled TCE product. He concludes that some of the TCE is lost to evaporation and that for the remainder, the soil column "entraps all the TCE" and "prevents the pure phase material from reaching the groundwater {pg. 38}. I respond to these opinions in Section 2.5.

The expert report from defendants and third party plaintiffs FDI and Hilton Reality, et al. concludes that "TCE-contaminated ground water emanating from the Princeton Gamma-Tech is a major source of the TCE contamination found in residential wells in the MTHD" (Environ, March 2000, pg. 6).

2.1 DNAPL Behavior

In hydrogeology TCE is categorized as a dense nonaqueous phase liquid, or DNAPL. The fate and transport of spilled TCE product is a specific case of the behavior of DNAPL in a geologic medium. Shepherd's {Sect. 2.2} conceptual model of DNAPL migration, and the implied vertical distribution of TCE as liquid, vapor, adsorbed to soil, and dissolved into vadose water and ground water {Sects. 2.3, 2.4}, does not consider significant aspects of PGT geology and spill history. The following comments provide a more complete description of relevant DNAPL behavior based in large part on recent knowledge described in the textbook Pankow and Cherry (1996). This conceptual model of TCE DNAPL migration from a surface spill differs significantly from that advanced by Shepherd in {Sect. 2.2} and applied by him in, among other places, {Sect. 4.2}. Specific implications are discussed in subsequent sections of this report.

Spilled DNAPL which infiltrates the soil first enters the interval between the surface and the water table known in hydrogeology as the vadose, or unsaturated, zone. The vadose zone beneath PGT consists of a heterogeneous mix of granular materials, including principally clay, silt and partly weathered shale; sand and gravel are encountered in the rear of the plant (e.g., PGT-2 [B-9] and MW-7D).

DNAPL behavior in such heterogeneous soils differs markedly from the behavior in homogeneous sands which seems to underlie Shepherd's conceptual model {Sect. 2.2} and calculations {Sect. 4.2}. In heterogeneous materials DNAPL makes its way preferentially along the most conductive pathways. This enhances DNAPL migration by restricting the volume of the medium to which the DNAPL is exposed.

Silt and clay strata may contain fractures as a result of desiccation and weathering, stress relief, and tectonic stresses. Fractures as small as 10-20 um in width can conduct DNAPL, and such apertures commonly are present in strata normally considered to be competent aquitards. (Pankow and Cherry 1996, pp. 72-75, 412). There is evidence of fracturing within the weathered rock at the Sites (e.g., boring logs for MW-6D, MW-16). This is as expected in light of the fractured nature of the parent shale rock and the demonstrated leaky character of the weathered materials.

Fractures or macropores in fine-grained materials preferentially facilitate and accelerate DNAPL migration through narrow gaps in an otherwise low-permeability matrix. This process is enhanced in wetter (but unsaturated) soils, where only the larger, more

conductive openings are accessible to the non-wetting DNAPL. (Pankow and Cherry 1996; Barbee 1994). A small fraction of a fractured clay volume participates in DNAPL mobilization. Accordingly the effective DNAPL residual saturation for DNAPL flow through fractured clay may be quite small and depends on the apertures and density of fractures and the rates of spillage versus dissolution and transfer to the clay matrix.

The downward pathway of DNAPL is interrupted where fractures terminate or offset, and DNAPL will pool laterally or vertically until another vertical fracture is intersected or breakthrough of a capillary barrier is achieved. Vertical migration of DNAPL through fractures appears to be enhanced where local ponding (perching) of infiltrating ground water occurs (Stephens et al., 1998); such conditions are expected transiently within the clay overburden.

Where DNAPL sinks below the water table it becomes a *submerged source* which very gradually dissolves into the passing ground water creating a long-lasting plume of dissolved contamination.

Known spills of TCE DNAPL at PGT consisted of repeated releases to the same location. Repeated releases of a DNAPL to the same location will have a strong tendency to follow and incrementally extend the same pathways through the soil. Field experimentation has shown that the same total volume of a DNAPL, if spilled in increments rather than all at once, penetrates much more deeply into a granular medium. Thus the effective horizontal cross-sectional area of a repeated spill has been found to be quite small and the vertical extent much greater than that calculated for a theoretical spill of the same volume with continuous horizontal wetting front (Pankow and Cherry 1996, pp. 406-408).In addition, in repeated spillage evaporative losses are expected to be reduced by relatively rapid descent of DNAPL into a pre-wetted (with prior DNAPL) pathway.

The distribution of TCE DNAPL after repeated spillage then will consist of a trail of residual DNAPL extending downward from the surface, pockets of DNAPL at various depths, and if sufficient volume was released, penetration of DNAPL into the ground water creating a submerged source.

TCE vaporizes readily and therefore a dense gaseous envelope of TCE vapor builds up around the DNAPL in the vadose zone. In a low permeability material such as silt and clay, TCE vapor spreading is driven principally by diffusion. Advective sinking of vapor is important in more permeable sands and gravels. The vapor plume expands outward and downward subject to spatial variations in conductivity, sorptivity and moisture content.

Infiltrating water that contacts either vapor or DNAPL residual within the vadose zone dissolves DNAPL constituents and carries that contamination to the ground water. In addition where vapor or DNAPL residual resides within the water table fluctuation zone, or where sufficient vapor accumulates at the capillary fringe to overcome capillary pressure, TCE dissolves into the ground water even in the absence of infiltration. Both of these processes create an *interface plume*. This thin, highly contaminated blanket of ground water then is conducted downgradient with the shallow ground-water flow.

Where an interface plume or very shallow submerged-source plume is carried beyond the limits of the soil gas plume, offgassing (volatilization) can occur from the ground water and extend detectable soil gas contamination in a direction aligned with ground-

water flow. However, offgassing is inhibited by even a thin (e.g., 1 m thick) layer of clean water such as accretes from infiltration; therefore such secondary soil gas plumes are spatially constrained by recharge rate relative to the rate of horizontal ground-water migration. (Barbee 1994; Rivett 1995). At the Sites, where effective porosity and permeability are low and ground water descends in response to natural recharge, septic leachate infiltration, and bedrock pumpage, the portion of a plume shallow enough to generate detectable soil gas is expected to be small and close to its source.

Once spillage ceases at a location, various depletion processes act to reduce TCE DNAPL and vapor concentrations within the vadose zone. After several years the residual distribution of TCE DNAPL may be quite irregular, perhaps limited principally to pocket depths or other discrete depths and the saturated zone if penetrated (Pankow and Cherry 1996, pg. 67). The vertical distribution of TCE vapor will then vary as a function of the residual distribution, of soil heterogeneity as it affects gas conductivity, and—beyond the limits of the primary soil gas plume—of offgassing from a migrating ground-water interface plume, if any. There may be little or no soil gas evidence of any submerged sources of DNAPL. (Rivett 1995).

2.2 Soil Quality Data at PGT

Shepherd relies heavily on the near absence of TCE in soil samples at PGT in his assessment of linkage between surface spills and ground water. However, for reasons explained in this section, this is a flawed and misleading approach. At the end of this section I review PGT leachate data which provide a much more pertinent characterization of the releases from the PGT septic system prior to May 1980 than does soil data utilized by Shepherd. I also emphasize that the dominant source of TCE at PGT likely was spillage at the dirt pile where no soil samples were collected.

Soil Testing Locations at PGT. Shepherd's interpretation of the PGT soil data is confused by apparent inaccuracies in his map of soil station location {Fig. 3.1}. His figure erroneously shifts the main septic field and associated borings B-# and LAT-# approximately 50 ft to the east of the location indicated in Sorge (1987b, Fig. 5. Similarly, {Fig. 3.3} shifts the transformer rocks approximately 10 ft to the north and enlarges the footprint in comparison to Sorge (1987b). I point out specific implications of these errors below.

Shepherd argues that soil quality data "show no TCE in subsurface soils consistent with...a surface release that impacted groundwater flowing toward the MTHD area or the RHMW public well" {pp.1, 9}. There have been several episodes of soil sampling at PGT. For the following reasons these soil quality data provide little information on the magnitude of TCE released to the surface or shallow subsurface at PGT.

- Soil samples at PGT have been collected exclusively from locations associated with the former and main septic systems and a gasoline tank. No soil samples have been collected from other actual or suspected TCE disposal areas at PGT including the dirt pile, the parking lot, and the transformer rocks bed. Nor has any effort been made to collect soil samples in a regular pattern across the property (in contrast to the investigation at FDI, for instance).

- As is discussed in Section 2.3, soil gas sampling results imply that the highest concentrations of TCE in the subsurface in August 1988 were in locations other than the septic system. No soil samples have been collected in these areas of highest soil gas concentrations, although that is a typical follow-up procedure to soil gas studies.

In short, the soil sampling program at PGT provides virtually no information on TCE releases except those from the septic system. Therefore statements in CRA (March 2000, vols. 1, 2) concerning what is "shown" by PGT soil quality data (including in comparison to FDI) should add that PGT's soil sampling network was unfit, and not designed, to detect releases other than those at the septic system.

- Shepherd states that soil samples B-6 and B-7 are located just west and east of, and within 10 to 20 feet of, the dirt pile area. This claimed proximity and the absence of TCE in the two 12 ft bgs soil samples is said to be "evidence that the dirt pile was not a source of TCE contamination to the ground water" {pp. 24-25}. However, as noted above, {Fig. 3.1} mislocates the soil stations of the B-# series. The figure also enlarges the dirt pile from the reported 3 to 4 ft diameter circle (Jennings 1992, pg. 18) to a 7 ft by 10 ft rectangle. Correcting these errors using Sorge (1987, Fig. 5) for the B-# locations and {Fig. 3.3} for the resized dirt pile location indicates that the dirt pile was east of both stations, approximately 40 ft from B-7 and 90 ft from B-6. These stations were too distant to characterize releases at the dirt pile, and B-7 is the closest PGT soil boring to the dirt pile.

- There are no soil borings near to the transformer rocks. For evidence of clean soils associated with the transformer Shepherd appeals to three TCE-free samples collected in 1996 at the base of a UST excavation cavity, 6.0-6.5 ft below grade {pg. 27}. He claims that these "GGT-#" samples were within 25 ft of the transformer rocks. However, after correcting the mapping discrepancies the soil samples prove to have been approximately 60 to 80 ft from the transformer. (The range reflects the length of the transformer rocks footprint). These stations were too distant to characterize the transformer rocks, and were the closest PGT soil samples to the transformer rocks.

Soil Testing at the PGT Septic System. Furthermore, for reasons discussed below, soil sampling performed at PGT provides only limited insight on TCE released by the PGT septic system. These sampling efforts are discussed chronologically in the following paragraphs.

- *April 1980.* Seven TH-series soil borings were sampled at one or more depths ranging between 3-8 ft bgs during April 1980; none detected TCE. However all of these borings were located at least five feet away from a septic field and all but one were at least 10 ft away (measuring the distance to laterals as shown in PJEC 1980c).[3, 4] Leachate is expected to move principally downward within the vadose zone. Therefore one cannot be sure that these soil samples intercepted leachate or leachate pathways from the former PGT septic field.

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[3] Seven borings were drilled and sampled, of which three were near to the main septic field, one was north of the overflow pit, and three were near to the original septic tank.
[4] The location of boring TH-2 is off the edge of my copy of PJEC (1980c) but can be estimated from PJEC (1980b and 1980c) to be approximately 5 ft north of the disposal trenches.

- *March 1983*. A single boring Hole #1 was made in March 1983 apparently within the main septic field 41.5 ft north of the "aeration tank" (PGT 1985b Tab. 16.3). No TCE was detected in four soil samples from the boring at 4.5, 4.9, 19.9 and 21 ft bgs. However, the main septic field apparently had been reactivated in October 1980 (NJDEP 1980) and flow through the septic system was high (indeed, it was too often beyond capacity causing overflows). Over the next 2.5 years presumably TCE-free leachate[5] flushed and promoted biodegradation of TCE within soils of the disposal bed, acting to remove TCE prior to the March 1983 sampling date.

- *May 1987*. All nine of the borings drilled during May 1987 (B-2 through B-10 of Sorge 1987b) were sampled from a depth of 12 to 12.5 ft bgs.[6, 7]

  Only the three borings within the abandoned overflow pit (a.k.a. "former septic system") (B-2, B-3, and B-4) actually sampled within the horizontal boundary of a septic field, and one of them detected TCE: soil sample B-3 (8 ug/kg TCE) was located in the center of the overflow pit immediately below the base of the pit (Sorge 1987b, pg. 6). The presence of TCE in boring B-3 within the overflow pit is evidence of TCE released to the soils by the former septic system.[8] The relatively small concentration of TCE in this sample and the absence of detected TCE in the other two borings do not imply that former releases of TCE to the overflow pit were small. As noted above, the overflow pit reportedly was reactivated in October 1980 and flow through the septic system was high (indeed, at times beyond capacity causing overflows) up to abandonment of the pit in March 1983. Over the 2.5 year period the presumably TCE-free leachate would have flushed and promoted biodegradation of TCE within the stony soils of the disposal bed, removing TCE. Biodegradation and TCE volatilization would have continued to deplete TCE content up to the May 1987 sampling date.

  The remaining six May 1987 borings were located around—but outside of—the main septic field. These six borings were poorly placed spatially and temporally to detect TCE released into the original main septic field. Reasons include:
  (1) The borings were located horizontally outside of the septic field;

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[5] I know of no leachate samples collected from the original septic system after October 1980 and simply assume that PGT no longer disposed of TCE to its septic system after the events of early 1980. The May 1987 detection of 147 ug/kg TCE in sludge from the former distribution box cannot be attributed to a particular period of release. The May 1987 detection of 15 ug/l TCE in the first stage of the active septic tank is definitely a counter-example to my assumption.

[6] This depth apparently was selected because it is just below the reported 12-ft depth of the main septic system trenches, the former overflow pit "laterals" (but seems unlikely), and the logged overflow pit "bottom" (Sorge 1987b, pp. 6, 10, App. C: B-2, B-3, and B-4). However, the depth of the original main septic field trenches is not clear from Sites documents. It may be less than 12 ft (indeed, Rzuczak [1994, pp. 130, 145] recalls a deepening of the septic system in 1983) and is described only as "variable" in PJEC (1980c).

[7] Two borings also were sampled at shallower depths, including B-3 (6 ft bgs) within the overflow pit and B-9 (2-4 ft bgs) north of the main septic field. Both contained no detectable TCE.

[8] Shepherd {pg. 19} suggests that TCE-contaminated PGT water supply well PGT-P1 could have been the origin of the TCE detected in boring B-3. That is incorrect. Use of PGT-P1 reportedly ceased some time prior to the January 1972 property transfer to PGT (Rzuczak 1994, pg. 37; Robertson, Freilich, Bruno & Cohen 1999a). The overflow pit was installed during PGT's ownership (Rzuczak 1994, pp. 123-24, 134) and therefore never received any effluent originating from PGT-P1.

(2) samples were collected vertically in "dry" materials (as logged in 1987, Sorge 1987b, App. C, B-5 through B-10; some samples have no information on moisture content). The main field was in use in 1987, and the dry samples suggest that when the main septic field is operating leachate does not migrate through the sampled locations;

(3) TCE was removed by subsequent TCE-free leachate. Even if, contrary to (2), the sampled soils did lie along a flowpath from the former main septic field, then they also lay along that flowpath subsequent to October 1980 when the original field was apparently reactivated, and subsequent to March 1983 when the current septic system was installed. Over the next 6.7 years presumably TCE-free leachate would have flushed and promoted biodegradation of TCE within soils of the disposal bed, removing TCE prior to the May 1987 sampling date. TCE volatilization also would have depleted TCE content during this period.

- *June 1987*. During the RI, boring SB-13 was advanced to 20 ft bgs "just downgradient" of the PGT main septic field. Two samples were collected: from 4-6 ft bgs and 14-16 ft bgs. No TCE was detected. As in the previous case, the boring was located horizontally outside of the septic field. In this case the entire boring from surface to bottom was logged as moist. If this was evidence of recent leachate rather than rainfall, then once again TCE likely was removed by flushing and biodegradation.

- *September 1996*. PGT has provided limited information on a September 5, 1996 soil sampling program which included ten LAT-# stations sampled 26-30 inches bgs (Robertson et al. 1999b; Accutest 1996). Samples reportedly were collected within or immediately adjacent to the main septic field (Robertson et al. 1999b, attached Sorge, Inc. Figure 2). The location and number of main septic system laterals shown in the provided figure are inconsistent with prior information on the system layout. The figure implies that the eastern five of the soil stations were collected substantially to the east of the former septic field and therefore did not characterize releases to the former septic field (compare to earlier documents Anon 1961, PJEC 1980c, or Sorge 1987b, Fig. 4).[9]

The western five LAT-# stations (#1,2,5,6,7) as posted in the Robertson et al. (1999b) location figure did lie within the main septic field (as delimited by the earlier documents) and did not detect TCE in 1996. These samples were collected from a depth immediately below the 2-ft bgs depth of the main system perforated pipes (Sorge 1987b, pg. 10). Once again leachate, presumably TCE-free, would have flushed and promoted biodegradation of TCE within these disposal bed soils for more than 16 years prior to the September 1996 sampling date. Volatilization upward through the trench fill also would have depleted TCE content during this period.

Shepherd opines that "if the septic system were a measurable source of groundwater contamination,…(then) TCE concentrations in the range of parts per million (over 1000 ppb) would be expected in the soils underneath the septic leach field" {pg. 19}. However, the foregoing paragraphs explain why the observed low to ND TCE concentrations in the available soil samples do not represent conditions within the septic system at the likely time of TCE releases through the PGT septic system (i.e., prior to its May 1980 hiatus).

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[9] If the main field overlies the former field as most information indicates, then the eastern five LAT soil stations also do not characterize the main septic field.

Septic System Sampling at PGT. Early septic system samples at PGT, including both septic tank contents and septic field effluent, provide a much more reliable indicator of the fate and transport of TCE in the septic system than do the soil samples described above.

- Leachate samples collected from the base of the overflow pit in 1980 confirm release of TCE into the environment and imply migration further downward to the ground water. The leachate samples characterize the very liquid which was proceeding to the ground water—rather than characterizing the soils which are many feet, many years, and an adsorption step removed from the transport pathway.

  The overflow pit was sampled from a standpipe which extended nearly 10 ft downward into the 10 ft-deep stone and soil-filled pit (Rzuczak 1994, pp. 123, 127) and contained 1400 ug/l TCE in 2/29/80, 6200 ug/l in 3/7/80 and 4600 ug/l in 3/13/80.[10] These are substantial aqueous concentrations of TCE in fluid poised to infiltrate to the ground-water table. There is every reason to expect that fluid within the overflow pit—and TCE within that fluid—migrated downward to the water table. Furthermore, these concentrations exceed the 1000 ppb criterion set by Shepherd to demonstrate a measurable source of groundwater contamination.

- Similarly, PGT septic tank leachate samples—which are one stage upstream of the leaching beds—indicate that in 1980 TCE was on its way to being released into the environment through the septic fields. Septic tank liquid samples from 2/29/80 (38 ug/l TCE), 3/7/80 (910000 ug/l TCE) and 3/13/80 (1100 ug/l), all collected prior to the temporary conversion of the septic tank to a holding tank on April 21, 1980, indicate the presence of TCE at substantial concentrations in the septic system leachate.[11]

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[10] PGT has assumed that the concentration units are erroneous on the Princeton Testing Laboratory (PTL) lab sheets which report the March 1980 septic system concentrations (e.g., PGT 1980a; PGT 1985, Table 16.2A). No justification is provided for this change which reduces reported concentrations 1000-fold. Furthermore, there is indication (in addition to a presumption of PTL competence) that the correct units were indeed mg/l as labeled on the lab sheets. The March 4, 1980 lab sheet presents its TCE results in "ug/l"; this is an example of PTL's considered use of the ug/l label when appropriate. An April 7, 1980 lab sheet from the same lab presents its TCE results in "mg/l"; this is an example of PTL's considered use of the mg/l label when appropriate—the reported results of 0.5 and 0.3 likely would have been below detection limits if the units were actually ug/l. This demonstrates that the lab generally was aware of the reporting units it was presenting and did switch back and forth between ug/l and mg/l.

[11] Shepherd {Table 3.1}, which summarizes PGT septic system sample results, contains multiple errors. The first two columns should be labeled as sludge samples, not liquid samples, and the units therefore should be ug/kg, not ug/l. The value of 1280 in the first column belongs to the second sample, not the first sample. A value of 75 ug/l toluene is missing from the second sample. The third column is a water sample from well PGT-P1, not a septic system sample, and therefore should be omitted from the table. The fourth column describes a sample which never existed, is apparently a misreading of WCC (1988, App. B), and should be omitted from the table. And finally, all but one of the many samples collected from the PGT septic system during 1980 are missing from the table. As one consequence of these errors, Shepherd {pg. 18} states incorrectly that "analysis of septic tank contents in February and April 1980 did not detect TCE in either sampling [sic] event". In fact, no PGT septic tank sample was collected in either month. In addition Shepherd {pg. 17} erroneously states that the PGT septic system was sealed from about 1980 to 1983; contemporaneous documents indicate that the system was sealed for only six months from late April through October 1980.

- I note that PGT or its contractor submitted eight liquid samples and one solid sample of unreported origin to Princeton Testing Laboratory during March 1980. The timing, analyte (TCE), and client (PGT) imply that the samples were a part of the PGT septic system investigation. All of the samples contained significant concentrations of TCE (300 to 12000 ug/l in the liquids; 190000 ug/kg in the solid). Specific implications await identification of these samples, which has been requested of PGT.

- I note that PGT or its contractor sampled water from a pair of shallow holes of unidentified specific location within PGT in late April or early May 1980 (JACA 1984, pp. 2-13, 4-11). The timing, analyte (TCE) and client (PGT) imply that these samples also were related to the septic system investigation and therefore likely were located near to one of the septic fields. The water samples all contained TCE at 68 to 75 ug/l (PTL 5/9/80). Specific implications await information on sampling location and depth (e.g., perched or water table), which has been requested of PGT.

Comparison of Shepherd's Opinions on TCE Releases at PGT and PCR. The May 2000 CRA investigation of soil and ground-water quality at Princeton Chemical Research (PCR) provides several examples of uncontaminated soil samples collected within purported source areas (leachate beds) overlying shallow ground water contaminated by those source areas—as interpreted by CRA {May 2000, Figs. 3.1 and 3.2}.[12, 13] Given clean soil samples overlying contaminated ground water within septic fields, Shepherd is willing to conclude for PCR that "TCE detected in groundwater within the confines of these sewer systems represents remnant TCE from historic surface percolation of wastewaters" {May 2000, pg. 17}. Precisely the same situation exists at PGT (except that most soil samples are only near to, but not within, the septic fields), and yet for PGT Shepherd uses the clean soil samples to preclude PGT as a source to ground water. Similarly Shepherd performs partitioning and leaching calculations based on PGT soil TCE and concludes that inadequate TCE exists in the soils to explain the underlying contaminated ground water {Sect. 4.1}. Using the clean PCR soils, he should come even more emphatically to the same conclusion. Yet he does not, instead dismissing the PCR soils data and concluding that the PCR septic fields are sources.

Shepherd's inconsistency reflects his response to the problematic nature of soil sampling at many hazardous waste sites. Unless the source area is large and homogeneous or accurately located, it takes a good measure of luck to find contamination using a soil sample within a three-dimensional potential source area. Samples of ground water and soil gas, both of which integrate over a larger measurement volume than soil samples (i.e., reflect TCE sources at greater distances), have a better chance of revealing contamination, and that is manifest both at PGT and at PCR. Former PGT consultant Dan Raviv, discussing another source at the Sites, agrees that "the inability to locate TCE contamination in soil [at FDI] does not indicate the lack of a TCE source. The use of ground-water sampling and ground-water flow is a more precise method of locating an historical TCE source." (Raviv 1993d, para. 3).

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[12] In particular, these soil station/ground-water station pairs, in leaching fields or adjacent to leaching pits, with clean soil and underlying TCE-contaminated ground water, include PCRSB-4/PCRMW-2+PCRSB-4gw, PCRSB-3/PCRSB-3gw, PCRSB-1/ PCRMW-3, PCRSB-10/PCRSB-10gw, PCRSB-13/PCRSB-13gw+PCRMW-1, and PCRSB-12/PCRSB-12gw.

[13] The two soil samples at PCR which did detect TCE were both from the saturated zone, where TCE is attributable to ground water collected within the soil sample.

2.3 Soil Gas Data at PGT

Shepherd considers the evidence of TCE in soil gas beneath PGT and concludes that it does not demonstrate linkage between the surface and ground water. He opines that the detected TCE originates from offgassing of TCE from underlying contaminated ground water. However, for reasons explained below, these conclusions are incorrect (Sections 2.3.1 through 2.3.3). The soil gas data is consistent with spills at PGT contaminating the vadose zone and underlying ground water. This conclusion is justified below both in its own stead (Section 2.3.3) and by comparison to findings at FDI (Section 2.3.1).

Inaccurate Mapping. Interpretation of the PGT soil gas data is complicated by the inaccurate station location information provided by PGT consultant Roy F. Weston. Weston (1988, Fig. 1), which posts station locations, contains distorted property and building dimensions, an erroneous scale (by a *factor* of 2.4), and incorrect placement of the septic fields and monitoring wells. It is therefore problematic to compare soil gas results with postulated TCE sources. For the sake of argument, I assume (reasonably, I think) in this section that the station locations in Weston (1988) were located "relatively" with respect to visible features such as building walls, pavement edges, transformer, or monitoring wells. For instance, where Weston (1988, Figure 1) shows that stations SG-28 and SG-78 bracket PGT-4, that is where I assume them to be located even though the well is substantially out of place in the figure. The soil gas stations within the rear grassy area could not have been oriented according to buried, concealed PVC septic system pipelines. Therefore I assume that they were oriented according to the building and parking lot, which implies that many of the samples were not within the horizontal limits of the septic field nor near to the former overflow pit. This is contrary to the portrayal of Weston (1988, Figure 1). Shepherd also reworks the soil gas station locations (compare Weston 1988, Figure 1 and {Figure 3.2} but does not explain his procedure.

Shepherd opines that PGT soil gas data "do not evidence a source of TCE on the PGT property" {pg. 9}. This opinion relies on three lines of reasoning, all of which are flawed. These three bases are discussed in Sections 2.3.1 Hot Spots, 2.3.2 Vertical TCE Gradient and 2.3.3 Offgassing.

2.3.1 Hot Spots

Shepherd's first rationale is that "if surface spills or other releases of TCE had occurred on the PGT property and were responsible for TCE contamination in the underlying water table, then the soil gas data would have ... localized 'hot spots' or areas where TCE concentrations were consistently and significantly elevated..., [but] the existing soil gas data collected at PGT do not exhibit [this] quality" {pg. 28}. However:

- The August 1988 soil gas samples were not collected within any of the known or suspected spill locations at PGT except for the main septic field. No samples were taken from within the overflow pit, from within the transformer gravel area, or from within the dirt pile. Therefore any peak TCE concentrations at these suspected hotspots are not exposed by the PGT sampling program.

- The main septic field had been operating with presumably TCE-free leachate for more than 7.5 years by the date of soil gas sampling. This promoted flushing and biodegradation within the field; this acts to reduce ambient TCE. Vaporization of TCE likely occurred upward, particularly through the fill materials of the trenches.

Infiltrating moisture, ubiquitous in a septic field, also is known to inhibit soil gas detection. (Recent rainfall can confound a soil gas survey). Almost all of the samples collected within the main septic field were drawn from 4 ft bgs, which is approximately 2 ft below the drain pipes and subject to both leachate flow and vaporization. These factors could have resulted in little detectable soil gas TCE within the main septic field samples in 1988 even though substantial TCE was released prior to 1981.

Even so, TCE and trans-1,2-dichloroethene (DCE), a degradation product of TCE, were detected at the eastern edge of the main septic field at SG-86 @ 4 ft bgs (65.5 nanograms/milliliter [ng/ml] TCE, 1.83 ng/ml DCE) and at two other locations at lower concentrations (SG-85, SG-81 both @ 4 ft bgs). This is consistent with TCE previously released to the septic field at concentrations sufficient to persist locally through the years of vaporization, flushing, and enhanced biodegradation. As discussed below it is also consistent with TCE vapor released from the dirt pile spills.

- Finally, contrary to the basis of the Shepherd claim, hot spots were detected by the soil gas samples. Indeed, a substantially contaminated area in the northeast portion of PGT was delineated by the soil gas study. This is the more conclusive because samples were offset from spill locations and because they detected residue of decade-old, or older, spills. TCE and its degradation products decrease over time due to several processes including vaporization, dissolution and advection (flushing), and (mostly biologically mediated) chemical degradation. The entire area of detected TCE beneath the parking lot and to the north through SG-86 comprises one or two hot spots of TCE vapor. Moreover, the TCE vapor concentrations are for the most part greater than those observed at FDI where Shepherd agrees that a hot spot exists (see Shepherd's error in comparison of units for PGT and FDI , below). The most contaminated individual samples of observed soil gas in August 1988 were at:
  SG-74 @ 1-15 ft bgs (522 ng/ml TCE, 51 ng/ml DCE) and SG-61 @ 4 ft bgs (97.7 ng/ml TCE, 3.35 ng/ml DCE) at northern edge of rear parking lot—adjacent to the known dirt pile spill area[14];
  SG-71 @ 1-15 ft bgs (875 ng/ml TCE, 131 ng/ml DCE) northeast of the transformer—adjacent to the known transformer rocks spill area[15]; and
  SG-77 @ 1-15 ft bgs (172 ng/ml TCE, 167 ng/ml DCE) and SG-47 @ 4 ft bgs (2.5 ng/ml TCE, 13.2 ng/ml DCE) along the north (rear) wall of the rear building—not far from the overflow pit.

- If PGT's spill location and volume estimates are correct then it is likely that the dirt pile spills are responsible for the hot spot of detected TCE vapor at PGT in 1988. The contribution by septic field releases to TCE vapor detectable in 1988 is uncertain due to probable lower volume, dissolved phase of the TCE, subsequent flushing and biodegradation, and possible masking by vapor from the dirt pile spills. The exception is at SG-77 and SG-47 which are not far from the overflow pit

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[14] The exact location of the dirt pile is uncertain. Shepherd {Fig. 3.3} places it farther to the east than the location of the tree (now stumps) with which the dirt pile was associated. I estimate the stumps location from photos of the site which I took in 1999.
[15] The exact location of the transformer rocks is uncertain. Shepherd {Fig. 3.3} places this feature farther to the north than any other map of PGT which I have seen.

and are somewhat removed from the other sources. If the overflow pit releases are not responsible at this location, then either an unreported spill occurred nearby or offgassing occurred from an underlying interface plume from the dirt pile spill (Sect. 2.1). The reported amount of TCE released at the transformer rocks is small; if this is accurate, then vapor generated from releases at the dirt pile dwarfed that from the transformer rocks spills except perhaps in their immediate vicinity. Indeed, the two stations closest to the transformer rocks, SG-33 @ 4 ft and SG-43 @ 4 ft, are distinctive from other stations at PGT in that they contain a high ratio of DCE to TCE implying advanced biodegradation. This suggests that they represent a different spill than the other stations, and this is reasonably interpreted to be a spill at the adjacent transformer rocks.

• Shepherd's analysis of the severity of observed soil gas contamination at PGT is erroneous and misleading because he uses incompatible units when comparing PGT results to FDI results. Data from the two sites are tabulated in different units which he mistakenly compares at face value[16]. A meaningful comparison of PGT and FDI requires that PGT's TCE results first be multiplied by 180. Shepherd does not do this.

He uses the FDI soil gas results, which he believes exemplify a source area, to demonstrate that PGT soil gas concentrations are diminutive and therefore uncharacteristic of a source area {Sect. 5.2}. However, in making this comparison Shepherd labels and applies PGT concentrations as if they were in ppb (parts per billion, which more properly for gasses is ppbv, parts per billion by volume) {e.g., pg. 24}. In fact the PGT concentrations are in ng/ml (nanograms per milliliter), unlike the FDI concentrations which are truly in ppbv. Concentration values expressed in ng/ml are numerically much smaller than those expressed in ppbv. This is not a simple typo. As a result of this units error Shepherd makes incorrect statements and draws incorrect conclusions.

Because of the units conversion error Shepherd fails to see that several of PGT's soil gas concentrations substantially exceed the highest observed value at FDI. Shepherd compares the highest concentrations of soil gas at FDI to soil gas concentrations at the PGT dirt pile and overflow pit. From the comparison he concludes that soil gas TCE at PGT is too low for the dirt pile and overflow pit areas to be sources {pp. 20, 24, 25, 42, 43}. But when the units are corrected the opposite conclusion must follow. The highest result for TCE soil gas at FDI was 4300 ppbv at station 236N220E @ 8 ft bgs. The highest soil gas concentration in the vicinity of the PGT dirt pile, at SG-74 @ 1-15 ft bgs, was 521 ng/ml=93780 ppbv.[17] This TCE soil gas sample exceeds the highest concentration at FDI by a factor of more than twenty. Similarly, at adjacent shallower SG-58 @ 4 ft bgs, TCE =32.49 ng/ml=5848 ppbv which also exceeds the peak FDI value. The highest soil gas concentration in the vicinity of the PGT overflow pit, at SG-77 @ 15 ft bgs, was 186 ng/ml = 33480 ppbv. This exceeds the highest FDI concentration by a factor of 7.8. Similarly, at adjacent shallower sample SG-47 @ 4 ft bgs, TCE=2.46 ng/ml=443 ppbv and DCE=13.17 ng/ml=3213 ppbv which is comparable to the

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[16] This is akin to numerically comparing two volumes when one is expressed in gallons and the other in tablespoons.
[17] The conversion from ng/ml to ppbv requires specification of ambient temperature, herein taken to be 60°F.

highest FDI value. Therefore, by Shepherd's analogy to FDI, the soil gas concentrations at PGT's dirt pile and overflow pit indicate PGT as a source of TCE contamination to ground water.

Shepherd also errs in his evaluation of soil gas near to the transformer rocks. He states that "if there had been significant amounts of TCE remaining in the soils near the transformer rocks at the time of the soil gas sampling, then [SG-33, SG-39 and SG-43] should have indicated concentrations of TCE in the range of 100 to 1500 ppb. This range of TCE concentration was detected in soil gas samples collected at the 4-foot depth at the former FDI property. [Conversely] TCE was detected at a range of 0.90 to 1.28 ppb in these three samples [at PGT]." {pg. 26}. Again equivalent units must be used. The TCE concentration range at these three PGT soil gas stations was 0.90 to 1.28 ng/ml, which is equal to 162 to 230 ppbv. Therefore by Shepherd's criterion these samples do indicate significant amounts of TCE remaining in the soils near the transformer rocks. Shepherd also ignores the even greater concentrations of DCE, a TCE degradation product, present at SG-33 and SG-43. At SG-33 TCE=1.28 ng/ml=230 ppbv and DCE=35.86 ng/ml=8750 ppbv, which is substantially greater than the maximum concentration in Shepherd's criterion.

In summary, Shepherd's first line of reasoning, that PGT is not a source because soil gas "hot spots" do not exist at PGT, is demonstrably false. High concentrations of TCE vapor were detected in the vicinities of the dirt pile, transformer rocks, and overflow pit, and these samples meet and exceed Shepherd's criterion for sources of TCE.

2.3.2 Vertical TCE Gradient

Shepherd's second basis for concluding that soil gas does not show a linkage between PGT's releases and ground water is that "if surface spills or other releases of TCE had occurred on the PGT property and were responsible for TCE contamination in the underlying water table, then the soil gas data would have...concentrations of TCE...at or near the surface in potential source areas that were elevated compared to the deeper samples...[but] the existing soil gas data collected at PGT do not exhibit [this] quality" {pg. 28, Sect. 5.2}. This opinion relies on his conceptual model of concentration gradients in {Sect. 2.4}.

This basis of Shepherd's argument is flawed both in application (due to shortcomings in the data used) and in theory (due to inadequacies of the conceptual model).

Model Application
Even if Shepherd's conceptual model of soil gas vertical gradient beneath a surficial spill is assumed to be valid, the available soil gas data at PGT is inadequate and inappropriate to apply the model to the suspected source areas.

- Shepherd's conceptual model applies to source areas. As stated above, the August 1988 soil gas samples were not collected within any of the known or suspected spill locations at PGT except for the main septic field. In particular, no samples were taken from within the overflow pit, from within the transformer rocks area, or from within the dirt pile. Therefore the vertical distribution of soil gas within these areas was not examined by the PGT sampling program.

- As stated above, the soil gas vertical distribution within the septic fields was substantially altered by leachate flow; the soil gas samples from 1988 are not expected to represent conditions during the pre-May 1980 period of alleged releases.

- Shepherd's conceptual model addresses the entire vadose zone from the surface to the water table. However, the soil gas data collected at PGT extend at the deepest stations to 15 ft bgs, and at most stations to 4 ft bgs. This is in every case less than half the thirty-plus foot distance from the surface to the water table. Therefore the soil gas data at PGT do not characterize the majority of the vertical profile upon which Shepherd's conceptual model-based opinion must depend. Unfortunately, the PGT soil gas data do not resolve this matter and there is no basis for Shepherd to extrapolate the available soil gas data into the unmonitored deep half of the vadose zone.

- As described below, at two (SG-71 and SG-74) of the three available PGT soil gas vertical profiles the maximum soil gas concentration is at a middle depth within the observed interval, not at top or bottom as claimed by Shepherd and required by the Shepherd conceptual model. Therefore the data is incompatible with the model and no conclusions should be drawn by applying the model.

- Shepherd claims that the soil gas stations SG-47 (4 ft bgs, TCE=2, DCE=13 ng/ml) and SG-77 (15 ft bgs, TCE=186, DCE=134 ng/ml) constitute a shallow-deep pair which (a) represents soil gas associated with the overflow pit and (b) demonstrates by an inferred vertical concentration gradient that TCE was not released at the overflow pit {pg. 20}. However, neither station was within ten feet of the overflow pit and therefore it is not clear whether these stations represent releases from it. Other possibilities include an unreported release at PGT or offgassing from an interface plume.[18] (The shallow ground water is contaminated at this location).

  If these two stations do reflect releases at the overflow pit, then the vertical distribution of TCE at the stations may reflect persistence of released TCE in soils near the base of the overflow pit. Indeed, the 1987 soil sample B-3 just below the base of the overflow pit detected TCE whereas B-3A within the overflow pit 6 ft bgs did not. Such a vertical TCE gradient within the abandoned overflow pit could exist because dissolved TCE, migrating freely downward with the leachate through the stony pit medium, was adsorbed by the native soils beneath the pit, and because the interior of the pit was subject to greater flushing, biodegradation, and vaporization than native soils during the period between October 1980-March 1983.

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[18] If there is an offgassing interface plume or very shallow submerged-source plume emitting detectable TCE soil gas anywhere at PGT, then it is strongest near its source. However, vapor from residual of the spill also is expected in proximity to the source and, as discussed above, soil heterogeneity and depletion processes can concentrate more vapor at mid-depth than near the surface. Therefore the "inverted gradient" soil gas samples in northeast PGT are consistent with a nearby dirt pile spill which led to either or both DNAPL residual vaporization and offgassing from an interface plume.

Furthermore, stations SG-47 and SG-77 are themselves approximately seven feet apart horizontally and 11 ft apart vertically. It is unfounded to claim that the difference in observed TCE concentrations at the two stations is due to the vertical separation rather than the horizontal separation. Finally, TCE biodegrades into DCE which also was monitored in the soil gas study. The observed ratio of DCE to TCE in the soil gas samples suggests that the shallower station sampled gas from a volume which had experienced greater degradation of the spilled TCE. This in turn implies that less of the original released material persisted to the time of sampling, contributing to the observed difference in concentrations between the samples.

Model Theory. Shepherd's conceptual model of the vertical gradient of soil and soil gas concentration induced by surficial or ground-water sources is overly simplistic and therefore its conclusions are unreliable. Processes ignored by the model can induce contrary gradients, mid-depth peaks, or other ambiguous trends at a source; the Shepherd model mistakenly interprets these as evidence of no source.

- Volatilization and degradation of soil gas TCE likely proceed more quickly nearer to the surface, acting to invert the shallower portion of an aging gradient from that expected of a recent spill. Furthermore, soil heterogeneity can be responsible for higher vapor concentrations at certain depths due either to concentration (e.g., pooling or adsorption) of DNAPL at these depths during mobilization or to higher conductivity at these depths allowing vapor movement. These processes, rather than offgassing from the ground water, can be responsible for soil gas vertical profiles at a source which are lower near the surface or which contain mid-depth peaks, contrary to the Shepherd conceptual model.

  An example of such an inverted shallow gradient exists at FDI, where Shepherd agrees that surficial spills created the soil gas plume. TCE soil gas concentration at station 180N300E was 110 ppbv @ 4 ft bgs and 1700 ppbv @ 8 ft bgs, a contrast of more than an order of magnitude (CDM 1993a, Fig. 2). This is qualitatively the same type of inverted soil gas concentration vertical gradient as exhibited at all the stations (SG-71, SG-74, SG-75, and pair SG-47/SG-77) upon which Shepherd exclusively relies to support his offgassing opinion {pg. 20}. Yet the origin of the TCE in soil gas at FDI (a surficial source) is precisely the opposite of that inferred by Shepherd for PGT (an offgassing source) from qualitatively similar data.[19,20]

  As another example, the ratio of DCE/TCE at soil gas station SG-71 decreases with depth, which is consistent with more advanced degradation at shallower depths.

  As a third example, at FDI the vertical distribution of TCE in soil samples (which was much more finely resolved than the soil gas vertical distribution) indicates mid-profile concentration peaks at three highly contaminated stations (180N220E, 220N220E, 180N300E). The soil gas data from PGT also imply that mid-profile

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[19] At 180N300E TCE concentration then declines in the deepest sample (83 ppbv @ 12 ft bgs), which is consistent with both a surface source and a near-surface gradient reversal by spill aging.
[20] The spill events at FDI are not well described and may have differed significantly from those at PGT. This alone could explain differences in soil and soil gas distribution at the two sites.

peaks occur. At SG-71 and SG-74 a composite sample was collected from the top to the bottom of the 15-foot sampling interval. In both cases the composite sample yielded a concentration higher than any of the depth-specific samples (and in particular, higher than the deepest sample). This implies that even higher concentration soil gas existed at some middle depth in each sample. Therefore the depth profiles at PGT are not simple inclines consistent with the Shepherd conceptual model, but rather curves with a mid-depth peak. By analogy to the FDI soil data these vertical profiles at PGT are evidence of a surficial spill.

In summary, the CRA (2000, vol. 1) vertical gradient model is simplistic, likely inappropriate for the spill scenario and geologic setting, and ignores depletion processes which lead to a shallow inversion of the gradient and are evidenced at FDI. The very little available data on vertical soil gas gradient at PGT (only two or three points per profile at only three stations), none in alleged spill areas and none in the lower half of the profile, is not conclusive of gradient shape or source vertical placement either absolutely or by reference to results at FDI.

2.3.3 Offgassing from Ground Water

Shepherd's third basis for concluding that soil gas does not show a linkage between PGT's releases and ground water attributes TCE in soil gas to offgassing from TCE-laden shallow groundwater migrating beneath PGT {Sects. 2.4, 3.3.1, 3.3.2, 3.3.3, 3.3.4}. The soil gas data collected in 1988 did detect TCE at PGT and Shepherd recognizes that this must be explained. However, his offgassing explanation is incorrect for the following reasons.

- Offgassing can occur from a very shallow plume (e.g., submerged less than a meter), and this mechanism may be responsible for some fraction of the TCE soil gas detected at PGT close to the dirt pile spill. However, Shepherd claims that all of the soil gas detected at PGT is caused by offgassing from a ground water plume. If so, then the soil gas distribution should echo the underlying contaminated ground water distribution at PGT and it most emphatically does not.

  For instance, soil gas TCE was either absent or, in two samples, at low concentrations on the west side of the property directly above shallow ground water with highest observed dissolved TCE. This was the case for soil gas stations beneath pavement, which Shepherd proposes as a gas-concentrating mechanism, as well as stations beneath grass cover. If TCE offgassing from ground water were elevating soil gas TCE at PGT, these many west side stations—and the several clean north and east side stations—should have detected TCE. On the contrary, even at soil gas station SG-79 adjacent to shallow well PGT-1—the most contaminated well in the MTHD/RHMW Superfund Sites and one drilled through pavement (boring log B-1)—no TCE was detected in the 15 ft bgs soil gas sample. At station SG-48, adjacent to the other side of this well, no TCE was detected at 6 ft bgs. Even where TCE was detected at depth on the west side, at SG-78 adjacent to shallow well PGT-4, the observed soil gas concentration was very small (4.04 ng/ml) compared to soil gas concentrations observed in the north and east portions of PGT. The soil gas study also drew samples from west of PGT, presumably in order to characterize the Mobil/Collins Auto property. The deepest of all soil gas samples sponsored by PGT were collected at two of these Mobil/Collins Auto stations, SG-68 and SG-69 @17 ft bgs. The samples were

some 45 ft west of the highly contaminated PGT-4 well and therefore likely overlay highly TCE-contaminated ground water. Yet the soil gas samples detected no TCE. These specific results and the more general absence of TCE in soil gas over much of the inferred shallow TCE plume are incompatible with a ground-water offgassing source for observed soil gas TCE. One must conclude that the much higher soil gas TCE concentrations in the northeast portion of PGT are not a consequence of offgassing from underlying ground water.

- Instead, soil gas at PGT is acting as a tracer for spill location, a task for which it is widely applied and much more sensitive and successful than for plume tracking (Rivett 1995, pp. 90, 91). Soil gas concentrations are high within the interior of PGT which is consistent with local spills at the dirt pile, transformer rocks and overflow pit.

- If, for sake of argument, one agrees with Shepherd that detectable soil gas does emanate from the contaminated ground water at PGT, then the observed soil gas at PGT argues strongly against his theory of off-property origin of the TCE at PGT. He claims that TCE-laden shallow ground-water plumes arrive at PGT from the north and west and suggests Mobil/Collins Auto and Montgomery Township Shopping Plaza (MTSP) as sources. Then by Shepherd's argument of soil gas as a ground-water plume tracer, swaths of TCE vapor should have been detected over the plumes as they enter in the west and north portions of PGT. But soil gas at PGT exhibits exactly the opposite distribution: soil gas TCE is absent to barely present throughout the west side of PGT and along the northern boundary.

- It is not surprising to find little or no detectable TCE in soil gas overlying a TCE-contaminated aquifer. A thin blanket of uncontaminated water at the water table is sufficient to inhibit TCE volatilization into an overlying vadose zone (Rivett 1995, the ES site). Only a very shallow plume, generally within a meter of the water table (i.e., an interface plume), is detectable in soil gas, and if such a shallow plume exists it would be "easily delineated by soil gas surveys" (Rivett 1995, pg. 90). At PGT a blanket of TCE-free water is expected to accrete from infiltration and septic leachate and to be stabilized by the downward vertical component of ground-water flow beneath PGT.

- Shepherd claims that "the distribution of TCE in the soil gas data…is inconsistent with the concept that the 8 ppb of TCE [in soil sample B-3] represents a zone of residual saturation [of TCE] beneath the leach field" {pg. 19}. I agree that TCE residual DNAPL is unlikely at the base of the overflow pit, but this is due to the dissolved (not DNAPL) phase of the released TCE and not to any reasoning based on the soil data. The detected TCE in soil beneath the overflow pit is meaningful. It provides additional evidence of dissolved TCE released to the pit. This is fully consistent with the TCE detected in overflow pit leachate (Sect. 2.2) and at a similar depth in nearby soil gas (Sect. 2.3.1).

In summary, offgassing is not expected except perhaps very near to the spill site. The observed soil gas distribution at PGT is inconsistent with an off-property west-side source and with an offgassing source of observed soil gas TCE, because the highly contaminated west-side ground waters generate little or no overlying soil gas TCE.

2.4 Shallow Ground Water at PGT

Shepherd agrees that the shallow ground water beneath PGT is contaminated with TCE {vol. 1 Sect. 3.2.1; vol. 2 Figs. 3.8, 3.9} and opines that PGT is not responsible for the contamination. In his opinion unreported TCE releases have occurred at two or more properties near to PGT, and TCE has then been conveyed with migrating shallow ground water to beneath PGT {pg. 27}. He claims that shallow ground water arrives at PGT from the north {pg. 27; also vol. 2 Fig. 3.5}. PGT is bordered on the north by Montgomery Center Shopping Plaza (MTSP). He also "logically suggests" that TCE-contaminated shallow ground water detected at PGT-1 and PGT-3 arrives from the west—in particular from the Mobil/Collins Auto Body property {pg. 30}. Finally, he perceives an inconsistency between the location of the "suspect sources" (transformer, dirt pile, septic systems) in the northeast portion of PGT versus TCE-elevated shallow ground water in the southwest portion of PGT {pg. 29}.

In this section I address direction of shallow ground-water flow at PGT and vicinity as rendered by Shepherd (Sect. 2.4.1), implications for sources of PGT ground-water contamination (Sect. 2.4.2), and my opinion concerning direction of shallow ground-water migration at PGT (Sect. 2.4.3).

2.4.1 Shallow Ground-water Flow at PGT per Shepherd

This section describes Shepherd's interpretation of the shallow ground-water flow at PGT, points out that this flow field is consistent with the dirt pile as the source of TCE contamination at PGT west-side wells, and explains inconsistencies which reflect interpretive errors.

- Shepherd claims that shallow ground-water flow mimics the topography of the ground surface and the directions of surface water runoff {vol. 2, pg. 16}. The highest land in the PGT vicinity (elevation ≥150 ft NGVD) wraps around south and east of PGT; the land surface declines to the north and west (Figure 3.3 and, at higher resolution, WCC 1988, Plate 3.1). Shepherd applies his topographic mimicry rule ("gravity drainage") to the shallow ground water and determines that flow is therefore to the north to west beneath PGT {vol. 2, Fig. 3-1}.

Then he apparently abandons the topography argument and appeals to shallow water level data at PGT to define the direction of ground-water flow beneath PGT {vol. 2, Sects. 3.2.3, 3.2.4, 3.4.1}. He prepares twelve water table elevation maps to that end. From the maps he infers a generally southerly flow at PGT with a component to the southwest in the west portion of the property {vol. 2, pp. A-15, A-16 and Figs. A-11 through A-22}. This southerly component is essentially the opposite of his claim based on topographic mimicry. He states that this direction also "is consistent with topographic grades and surface water flows in this area of the Sites" {vol. 2, pg. A-16}, but it is not. The topography falls off to the north and west at and north of PGT, as he makes clear in his first claim and as is manifest from topographic maps including {Figure 1.1}.

In Shepherd's opinion his second claim (water-level based) displaces the first (topography-based). He does not reconcile water level data and topography. The direction of flow which he ultimately adopts for PGT is contrary to that indicated by the topography and is based on water level data from five wells on the PGT

property. (Section 2.4.3 provides a coherent theory of shallow flow which accommodates topographic and hydraulic features of the Sites).

• Ten of Shepherd's twelve shallow water level maps for PGT indicate a flow direction which is west-southwest across the property (ignoring extrapolated dotted contours which are not based on data). A more strongly southern direction of flow for the eastern portion of PGT is inferred in only two of the figures, namely {vol. 2, App. A, Figs. A-20 and A-22}. The difference occurs because only those two water level surveys included well MW-9S.[21] These two figures, therefore, should be viewed as Shepherd's most informed opinion on shallow ground-water flow direction in the vicinity of PGT.

• Shepherd's direction of shallow ground-water flow at PGT explains observed TCE contamination at all of the PGT west side shallow wells (PGT-1, PGT-3, and PGT-4). All of the known and suspected TCE sources at PGT are located in the northeast portion of the property. According to Shepherd shallow ground-water flow at PGT is to the south, curving to southwest; therefore TCE in the shallow ground waters on the west side of PGT reflects—indeed is strong evidence of—releases of TCE to ground water in known/suspected source areas in northeast PGT. This is a rather obvious conclusion, although it is opposite to that drawn by Shepherd from the same direction of flow, source distribution, and ground water quality data {pg. 29}.

• *The PGT-2/MW-7S Test.* Wells PGT-2 and MW-7S are located in the northeast corner of the PGT property. They have the highest monitored water level elevations of all shallow wells evaluated by Shepherd. Both wells consistently have contained TCE-contaminated ground water with historical TCE maxima exceeding 600 ug/l. A viable theory of shallow ground-water flow at PGT must explain the TCE contamination at these wells.[22]

Shepherd's theory of the site does not explain the shallow contamination at PGT-2 and MW-7S. Because he interprets shallow flow to be toward the south-southwest at PGT, he blames Mobil/Collins Auto only for the contamination in the western portion of PGT {vol. 2, pg. 47}). He has placed a shallow flow divide within MTSP to the north of PGT {vol. 2, Fig. 3.5, pp. A-15 to A-17}, implying that shallow flow will proceed from southeastern MTSP onto PGT and through these two wells. Therefore for his theory to explain the TCE in PGT-2 and MW-7S an unknown, unsuspected source of TCE would have to exist in the southeastern corner of MTSP. Shepherd makes no mention of such a hypothetical source, and there is nothing in the Sites data to suggest such a source. He does not otherwise explain the contamination at these wells.

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[21] The water elevation at MW-9S on 3/16/92 is uncertain. It is reported as 108.33 in {vol. 2, App. A, Fig. A-20}, as 108.57 in DRAI (1/22/93, Fig. 3) and as 109.67 in CDM (1993, Table 4-1). The CDM value is from an independent measurement on the same day. Use of an inappropriate top-of-casing elevation (inner and outer casings both are steel) is likely responsible for the relatively large difference between the CDM and DRAI measurements, but there is insufficient information to determine which casing was used or which value is correct.

[22] PGT-5, with its single TCE analysis yielding 880 ug/l in 1992, also may be added to the PGT-2/MW-7S test.

- Shepherd's placement of a shallow divide within MTSP rather than at PGT is without technical basis, and it is a keystone of his conceptualization of Sites hydrogeology. Peak observed shallow water elevations are *within* PGT at PGT-2, MW-7S, and PGT-5, not at MTSP (Section 2.4.3). Topography is high at PGT (consider the 142-ft contour in WCC 1988, Plate 3.1) and consistently declines toward the north from PGT, beginning with a rapid descent of approximately eight ft at the PGT-MCPS property boundary. The topographic mimicry rule need not be violated at and to the north of PGT.

  PGT consultant DRAI (1992a, pp. 5, 8) also places the shallow ground-water elevation divide within PGT, and attributes it to topographic effects.

In Section 2.4.3 I offer an interpretation of the shallow ground-water flow field compatible with water elevation data, topographic data, and effects of pumpage, which does explain contamination at MW-7S, PGT-2, and other shallow wells in the PGT vicinity.

2.4.2 Non-PGT Sources of TCE in PGT Shallow Ground Water

Mobil and Collins Auto/Thul's. Shepherd has suggested that Mobil or Collins Auto/Thul's would "more reasonably explain the TCE concentrations in the groundwater at PGT-3 (in the southwest corner of the [PGT] property) than a release on the PGT property" {pg. 30; vol. 2, pg. 47}. He also implies that PGT-1 is contaminated by Mobil or Collins Auto/Thul's activities {pg. 30}. Finally he states that the "middle plume" of shallow TCE contamination originates in part at Mobil/Collins {vol. 2, pg. A-21 and Figs. A-24 and A-25}. However, environmental data and Shepherd's conclusions on flow direction imply that Mobil/Collins is not responsible for the TCE at PGT.

Shepherd is of two minds concerning the direction of shallow ground-water flow on the west side of PGT and at Mobil/Collins Auto. On the one hand, his interpolation of water level data demands that flow is toward the south to southwest {vol. 2, Sect. 3.4.1, Figs. 3.5, A-8 insert, A-9 insert} and so he opines quite clearly that "groundwater flow in the shallow hydrostratigraphic unit in this area [west portion of the PGT property] is to the south-southwest" {vol. 2, pg. 53}. On the other hand, he speculates that "flow from the Thul's [Mobil/Collins Auto] property might also be to the southeast" {vol. 2, pg. 47}.

He attempts to explain this inconsistency as the effect of seasonal factors or of pumpage at PGT-P1 or RHMW. But seasonal variation in shallow flow direction is not observed or expected at any location at the Sites; in particular the shape of the shallow piezometric surface at PGT is nearly identical in all rounds of measurement and never suggests flow to the southeast. Pumpage at PGT-P1 ceased before 1972, long prior to any of the water quality monitoring at PGT. The stability of the observed water quality distribution at PGT (e.g., the ranking order of contamination) indicates that PGT-P1 pumpage had no detectable impact on the observed TCE distribution. And analysis of shallow ground-water flow direction (Section 2.4.3 and Figures 2.1, 3.1) does not suggest that Mobil/Collins Auto lies within the zone of capture of RHMW.[23]

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[23] Shepherd's opinion that RHMW pumpage draws shallow ground water southeast from Mobil/Collins Auto towards RHMW implicitly acknowledges that shallow ground water at more proximate PGT also is drawn toward RHMW.

- Shepherd concludes without qualification that "groundwater flows onto the PGT property from the north in this shallow water table zone [west portion of the PGT property]" {vol. 2, pg. 53}. But then he cannot move TCE from his postulated Mobil/Collins Auto source to PGT. According to his flow direction interpretation, any TCE contamination arriving at PGT in the shallow ground water from other properties must pass through the north through northeast side of PGT. This rules out the Mobil station and Collins Auto/Thul's facilities as sources of shallow ground-water contamination at PGT.

- Furthermore, soil gas samples were collected in 1988 at seven locations west of PGT on the former the Mobil station and Collins Auto/Thul's property. No TCE was detected in any of these samples, including two which were the deepest of all soil gas samples collected by PGT. This is additional evidence that Mobil/Collins Auto was not a source of the TCE detected in the shallow ground water at PGT.

- Shepherd infers that there are three shallow TCE-contaminated ground-water plumes at the Sites. His "middle plume" encompasses all of PGT and extends east to Merritt Lane, west to the Wm. Penn and Texaco stations, north into approximately the lower third of the MTSP and south approximately 100 ft beyond the Town & Country Animal Hospital {vol. 2, Figs. 3.8, 3.9, A-24, A-25}. Except for the contamination at PGT and toward the southeast this shallow plume is imaginary. There is no shallow water quality data to delineate its shape or boundary beyond PGT except at MW-9S to the southeast. Shepherd claims that this middle plume "originates in the southwest corner of the MTSP and near the former Thul's Mobil Station" {vol. 2, pp. 19, A-20 to A-21}. However, his imagined plume boundary is not even consistent with this statement because the plume is extended beyond these properties to the west and south.

  Most importantly, as stated above, his projection of a shallow plume extending from a western source or sources toward the east is incompatible with his interpretation of south-southwest shallow ground-water flow at PGT.

  Finally, the middle plume is in essence a stationary bulls-eye of TCE centered on PGT. It attenuates away from PGT in all directions, including toward the west. It is illogical to infer that the plume originates at its western edge rather than at the concentration center of the bulls-eye. In summary, the implication that Mobil/Collins Auto is a source of TCE in the real PGT plume, rather than a recipient of TCE from PGT, is without basis and leads to irreconcilable inconsistencies in argument.

MTSP. Shepherd invents two sources, neither of them detected by the Sites environmental data, in order to justify his middle plume without implicating PGT. The first is Mobil/Collins Auto, which is discussed above. The second is MTSP, which in his opinion releases sufficient TCE to fill in the northern portion of his middle plume and contaminate wells PGT-1, PGT-4, PGT-2, MW-7S, MW-7D and MW-7DD. He believes that a shallow ground-water divide exists within MTSP to the north of PGT, inducing southward flow from MTSP to PGT. (As noted earlier, on this matter Shepherd departs from the view of former PGT consultant Dan Raviv, who places the divide within the PGT property [DRAI 1992a, pg. 8]).

- I address the hydrogeologic aspects of shallow flow divide placement in Section 2.4.1, where I conclude that the divide or water level high lies within PGT and not to the north. This implies that ground-water flow at MTSP will carry an MTSP TCE source, if any, toward the north away from PGT.

- Even if dissolved TCE emanated from the SW septic system at MTSP and even if one adopts Shepherd's opinion on direction of shallow ground-water flow, the TCE would not be carried to PGT. The original septic field was located west of the SW leg of the plaza, due north of the former Mobil/Collins Auto property. According to Shepherd shallow ground-water flow is to the southwest in this vicinity {vol. 2, Figs. A-8 inset, A-9 inset}. This would convey any contamination from the MTSP septic field away from PGT.

As shown in section 2.4.3, shallow flow at PGT follows a somewhat different path than that interpreted by Shepherd. Even so, both interpretations of flow direction rule out Mobil/Collins Auto and MTSP as sources of the ground-water contamination observed at PGT. The direction shown in Section 2.4.3 also explains observed contamination in all of the PGT wells, MW-9S/D, and Mobil wells.

2.4.3 Shallow Ground-water Flow at PGT

Shepherd misrepresents my opinion when he states that I dismiss the significance of shallow ground-water flow at the Sites (also see Section 3.2). As I pointed out in Chirlin (2000, pg. 4-18) lateral flow within the weathered materials and/or uppermost bedrock is demonstrated by, among other evidence, the migration of TCE within this zone at PGT. I agree with Shepherd that ground water flows horizontally over distances at least as wide as the PGT property (300+ ft), and probably farther. And as described below, shallow ground-water flow has carried TCE contamination outward from the spills in the northeast portion of PGT.

On one date, August 11, 1993, a set of water level observations was collected by a PGT consultant which included all five of the PGT-# wells, MW-7S, and MW-9S, among others (DRAI 1993b, Table IV). This is the most complete and informative of all shallow water elevation data sets for the PGT vicinity because it alone includes PGT-5 located just north of the PGT building.[24] I have interpreted shallow ground-water flow direction using these August 11, 1993 measurements.

- The water level at PGT-5 is not fixed precisely due to lack of an elevation measurement for its top of casing. A reasonable estimate for top of casing[25] implies

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[24] Well PGT-5, known as MW-5 in PGT facility reports, was installed and named in 1992 in conjunction with an underground storage tank removal (Sorge 1992b, pg. 1).

[25] PGT does not know the elevation of the top of casing at PGT-5 (Robertson, Freilich, Bruno and Cohen 1999a). I estimate it based on a ground elevation of at least 142.5 ft NGVD (WCC 1988, Plate 3.1; also comparing to the T. T. Moore (1988) and Robert Buda Assoc. (1992) surveyed ground elevation of 142.5 at PGT-1, which the WCC 1988 Plate 3.1 topo implies is lower than PGT-5). The well has a flush mount inset of -0.5 ft (Sorge 1992b, App. F), so using the ground elevation estimate of at least 142.5, the inner casing elevation is at least 142.0 ft NGVD. This implies that water elevation at PGT-5 on August 11, 1993 was at least 111.08, which was at least 0.2 ft higher than at any other well on the property. Actually, contrary to the DRAI (1993b, Table IV) table heading, the measurement point at PGT-5 was probably the outer casing; this would increase the water elevation by 0.5 ft to at least 111.58. This is inferred from the DRAI (1993,

that the water elevation at PGT-5 is higher than that at any other shallow well at PGT, which includes wells in every compass direction from PGT-5. This is conclusive evidence that a shallow ground water divide or peak exists within the PGT property. Shepherd does not use the PGT-5 water elevation point in his analyses.

Figure 2.1 presents interpolated shallow ground-water contours at PGT and vicinity based on the August 11, 1993 data. The configuration of the contours, dictated in large part by the observed data, raised some questions whose answers in turn helped to refine the contours.

(1) Why does a ground-water high exist within the northeast portion of PGT? One factor is enhanced recharge within the grassy area, due both to septic leachate and to natural rainfall percolating through the relatively sandier fill (the rear of PGT is filled), through the 12-ft deep trenches in the main septic field, and through the 10-ft deep stony fill in the overflow pit (Chirlin 2000, Sect. 4.2.5.5). CDM (1993, pg. 4-6) also has suggested this mechanism. Another factor is that the shallow ground water surface echoes the topography, a point also made by PGT consultant DRAI (1992a, pp. 5, 8, Fig. 3). Absent pumpage by RHMW, there would be a high aligned along the topographic ridge which wraps around the south and east of PGT (Figure 3.3). However, as discussed in the next paragraph, pumpage at RHMW has created a local piezometric depression which bifurcates the high. The northern leg passes through PGT—which lies on a lobe of high land[26]—and rejoins the topographic ridgeline farther to the northeast (also Figure 3.1).

(2) Why does the water level surface decline to the south, contrary to the topography? The relatively low shallow water elevation at MW-9S, in spite of relatively elevated topography, likely is due to downward leakage to satisfy the demand of nearby RHMW. Drawdown within the bedrock is very high in this area: MW-9D is drawn down more than 20 ft (CDM 1993, Fig. 4-7). Not surprisingly, the shallow unit also is affected (contrary to previous statements by all investigators). There is evidence of the influence of RHMW on the shallow zone. MW-09S was drawn down 0.23 ft by the December 1986 6-hour pump test of RHMW (Woodward-Clyde Consultants 1987, App. A). The drawdown was gradual, and it continued after the test ended and at least up to the final data point some three hours after shutdown. Thus shallow water elevation in the vicinity of MW-9 is chronically depressed due to pumpage of RHMW. The magnitude of this effect is not characterized by the WCC pump test; leakage and recovery are too slow. The horizontal extent of this depressed shallow zone area around RHMW is uncertain but is interpreted to be aligned along-strike over the area of depressed bedrock piezometric surface (Figures 3-1, 3-2). One consequence of this area of depressed shallow

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Table IV) use of an outer casing measurement point at PGT-1, which is the other flush-mounted well at PGT. Use of the outer casing at PGT-1 is evident because the casing elevation of 142.5 ft in DRAI (1993b, Table IV) matches the surveyed top-of-casing elevation of the steel outer casing in the Aqua Firma Surveys Inc. (1987), T. T. Moore (1988), and Robert Buda Assoc. (1992) surveys of PGT-1. (The inner PVC casing is approximately 0.5 ft lower in the surveys).
[26] This is evident by tracing the 142-ft elevation contour of WCC (1988, Plate 3-1).

water level is a "saddle" in the shallow piezometric surface.[27] For illustrative purposes I indicate this feature using 108-ft contours in Figure 2.1, but precise placement is not fixed by the water level data (see Sect. 3.4.2).

• Once the effect of long term pumpage by RHMW is recognized, a shallow piezometric surface interpretation follows which is consistent with both the effects of topography and the observed water levels at PGT.

• The shallow flow field of Figure 2.1 explains the observed TCE distribution at—and somewhat beyond—PGT. Notably, a single source at the dirt pile, extended somewhat by DNAPL lateral flow and diffusive vapor migration (Sect. 2.1), is sufficient to explain contamination over a wide area. This is due to ground-water flow divergence caused by the water level high which extends through the source area. (The ground-water quality impacts of the PGT septic system sources are difficult to differentiate from those of the dirt pile source; see below).

(1) TCE contamination at MW-7S, PGT-2, PGT-5 , PGT-1, PGT-4 and PGT-3 all follows directly from a spill at the dirt pile, migration of DNAPL, vapor, and/or dissolved TCE to the water table within northeast PGT, and the ground-water flow field of Figure 2.1.

(2) The southerly ground-water flow direction on the east side of PGT impels shallow ground water from PGT towards RHMW. As discussed above with respect to MW-9S, RHMW-induced leakage is expected to carry shallow ground water downward as it approaches the vicinity of RHMW. The MW-9 nest is located slightly east of the pathway from the dirt pile to RHMW as indicated by the contours of Figure 2.1; it is therefore consistent that MW-9 is only slightly contaminated with TCE. The downward leakage of contaminated ground water from the weathered zone to bedrock and continued downward migration within bedrock to the depth of the RHMW open hole interval may be responsible for the essentially uniform vertical distribution of TCE at MW-9 (as measured in 1992 by CDM [1993]).

(3) Former PGT supply well PGT-P1 contained TCE at up to 380 ug/l in three or four samples. The well was located adjacent to the front steps of the plant and according to Figure 2.1 is downgradient of the dirt pile spill area. PGT-P1 is open to a depth interval of 34 – 134 ft bgs which includes the shallow ground water zone.

(4) The Mobil gas station on the corners of Routes 518 and 206 had a water supply well which contained 24 and 120 ug/l TCE in its two sampling events in 1983. The depth of the well is unknown, but other nearby commercial wells such as PGT-P1 (134 ft) and Texaco (180 ft) are relatively shallow. Mobil may even open to the shallow unit as does PGT-P1. The portion of the TCE plume

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[27] The saddle is inferred from high shallow water levels along the topographic high to the southwest (as detected at MW-10S), depressed water levels to the southeast induced by drainage to RHMW (as detected at MW-9S), low water levels to the northwest (as expected from topography), and high water levels to the northeast at PGT (as detected by the PGT-# wells and MW-7S).

emanating southwest from PGT is the likely source of adjacent Mobil/Collins contamination.

(5) The flow field of Figure 2.1 passes the MW-7S/PGT-2 test of Section 2.4.1: shallow ground water migrates from the vicinity of the dirt pile spill towards each of these wells.

(6) It is difficult to differentiate effects of septic system releases on the PGT ground-water plume because of masking by the dirt pile spills and because of timing of ground-water samples. Evidence strongly argues that releases occurred from the septic system (Sect. 2.2). The locations of the septic fields are such that TCE released to ground water likely merged into the greater PGT plume created by the dirt pile spills. The septic system sources consisted of dissolved TCE in water and therefore were less concentrated and probably less persistent than DNAPL. Furthermore the septic system areas were flushed by presumably TCE-free leachate for approximately seven years before ground-water quality data was collected at PGT. Therefore the bulk of the TCE released through the septic systems likely had migrated off-property before ground-water monitoring commenced at PGT.

(7) The observed August 1988 soil gas distribution is consistent with the principle TCE source area being the dirt pile. Soil vapor TCE, still detectable at substantial concentrations in northeast PGT in 1988, likely reflects DNAPL residual saturation within the vadose zone, perhaps trapped by pavement cover but nonetheless originating nearby. As noted earlier, an interface plume may extend beyond the soil vapor envelope around the dirt pile DNAPL trail, perhaps contributing offgassed TCE to the inverted vertical TCE distribution remarked upon by Shepherd (Sect. 2.2.2). TCE at 65.46 ng/ml (11782 ppbV) was detected approximately 70 ft north of the dirt pile on the eastern edge of the main septic field at SG-86 @ 4 ft bgs, and lower values were observed to the east and west thereof (SG-85, -81, -80, and -75). This may reflect migration of TCE in vapor or interface plume form toward the northwest to northeast from the dirt pile; septic field releases are the alternative source of these vapors.

(8) It is difficult to discern whether, or to what degree, observed TCE in the shallow ground water at PGT reflects a vadose zone DNAPL source (with leaching and/or an interface plume), a submerged DNAPL source, or both. The soil gas data imply that vadose zone DNAPL exists (as of 1988), and therefore leaching and perhaps an interface plume are expected. However, the size and pattern of spillage implies that DNAPL likely entered the ground water (Sect. 2.5). Furthermore, the persistence of TCE two decades after the last likely spillage suggests that a submerged source was active.

In summary, Shepherd proposes one facility (Mobil/Collins Auto) to contaminate some PGT wells (PGT-1 and PGT-3) and another facility (MTSP) to contaminate other PGT shallow wells (apparently PGT-2, PGT-4, PGT-5, MW-7S).

However, there is no data indicating that either facility actually is a source of TCE. Furthermore, shallow ground water does not flow in the requisite direction to implicate either Mobil/Collins Auto or MTSP. The more straightforward and defensible explanation is that one facility, PGT, is responsible for the contamination at all of the shallow PGT

wells. There is testimony of TCE spills, and calculations imply that DNAPL TCE likely reached the shallow ground water (Sect. 2.5). There is leachate, soil gas, and limited soil quality evidence of "linkage" of spilled TCE to the ground water at PGT. Based on observed water elevation data, shallow ground-water flow proceeds in the appropriate directions to have created the observed shallow TCE contamination observed at PGT and extending toward RHMW and to the north.

2.5 TCE DNAPL Volume, Evaporation, Infiltration, and Biodegradation

Shepherd estimates the volume of TCE discharged to the surface at PGT by considering the two confirmed spill locations: the dirt pile and the transformer rocks. He calculates the volume of TCE evaporated during and after these spills and the volume of TCE retained within the soil column as residual liquid within the pore space using methods described in {Appendices E, F}.

He concludes for the dirt pile that over a four year period from 1974 to 1978: 120 to 250 gallons of TCE was spilled (depending on the methanol fraction of the spilled volume), 24.5% of the applied TCE evaporated, and the remaining 90.6 to 181 gallons of TCE seeped into the soils and was immobilized as residual DNAPL within the soil pore space. He also claims that TCE DNAPL degradation would be enhanced by its co-disposal with methanol, the latter serving as an energy-rich substrate for microbes mediating TCE breakdown {Sect. 4.3}.

He concludes for the transformer rocks that 2.5 gallons of TCE was spilled over a five year period from 1975-1980 resulting in 2.0 gallons or less of TCE seepage into the soils, and that this TCE likely further degraded or attenuated otherwise within the top six inches of the soil column {pg. 36}.

• Shepherd makes several assumptions in his analyses which are unrepresentative of spill conditions and PGT environmental properties. In addition he uses estimation methods which are inapplicable to PGT conditions and also are very unreliable as a general matter. As a result his calculations underestimate the DNAPL volume released and depth penetrated. The methods and results are not reliable for the purpose at hand—to assess the likelihood or volume of DNAPL migration to the shallow ground water 30 to 35 ft bgs at PGT.

• Shepherd estimates the volume of TCE released at PGT by making assumptions which minimize that volume.

(1) He considers releases to have occurred only at the dirt pile and transformer rock, although these locations are simply those about which two former employees have personal knowledge. PGT's routine practice was to pour its used TCE on the ground at the plant. It is certainly conceivable that additional spills also took place.

(2) He considers releases at the dirt pile only between 1974-1978. He also calculates this period as four years rather than five {36}. TCE also was in use at PGT in late[28] 1972, 1973, 1979, and the ignored year of 1974 and/or 1978 (e.g., Feenstra 1995, Table 1). Disposal practices apparently did not change until after January 1980

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[28] According to Davison (2/16/94, pg. 303), PGT began operations at the Rt. 518 facility in October 1972.

when NJDEP discovered TCE in the septic system, investigations commenced, and PGT switched its degreasing solvent from TCE to acetone (Jennings 1992, pp. 41, 53, 54, 59, 80). PGT did not switch its solvent until at least March 1980 (PGT 3/11/80; TMHD 3/24/80). If releases occurred at the same rate over the entire 7.33-year period from October 1972 to 1979 inclusive, then assuming the same average monthly spillage as does Shepherd at {36} (5 gallons TCE/month) the total spilled volume would be 440 gallons which may be visualized as ten 44-gallon drums of TCE. If the spilled fluid was 50% methanol, then the spilled volume would include 220 gallons or 5 drums of TCE and an equal amount of methanol.

- Shepherd evaluates evaporation at the dirt pile but makes unrealistic assumptions that lead to an overestimate of evaporative losses.

    (1) He begins by making the following assumption: the spill is uniformly spread over a 2 by 4 ft (8 ft^2) surface area with uniform vertical distribution of TCE from the surface to 0.5 ft bgs. Reality differs significantly from this assumption and estimated evaporative losses are much reduced as a result. Individual spills likely were released to an area half that size or less. When pouring liquid from a bucket I pour to one spot, particularly if the bucket is heavy (e.g., contains 5 gallons of liquid). I know of no explicit discussion of the footprint of the pour; Jennings (1992) mentions only the size of the dirt pile (a cone with a diameter of 3 to 4 ft). It seems most likely that he poured onto a modest portion of the same part of the dirt pile each time. It is unlikely that he poured over the entire dirt pile as assumed by Shepherd. A one-half as large footprint (2 ft x 2 ft, still probably too large) will lead to nearly double penetration depth and proportionately smaller evaporative loss.

    (2) Pouring repeatedly into the same DNAPL-wetted, matrix saturated pathway likely causes DNAPL to move quickly downward to depths where evaporation no longer is significant. This effect, although difficult to quantify, may have conducted much additional TCE beyond the effects of evaporation and is ignored by Shepherd.

    (3) The particular evaporation models adopted by Shepherd appear to have been misused, even for the hypothetical scenario he proposes. This is suggested by the Shen model assumption of clean soil cover in its variable "dsc". However, the explanation in {Appendix E} of the methodology is incomplete; in particular it is unclear how and upon what basis the Shen and integrated RTI models were used in tandem.

- Shepherd applies the dirt pile fractional evaporation rate directly to the transformer rocks, so the above objections also apply to that calculation.

- Shepherd estimates vadose zone immobilization of DNAPL at the dirt pile but makes unrealistic assumptions and uses inappropriate conceptual models which underestimate DNAPL penetration depth.

    (1) He begins by considering the "retention capacity" of a 10 ft by 10 ft by 33 ft deep soil column with an assumed (10% of pore volume) residual saturation capacity. He thus calculates that the retention volume of the soil column is 740 gallons TCE which exceeds his estimated DNAPL spill volume of 181 gallons. However, this method,

which uses laboratory-based residual saturation capacity values, has been discredited. Field experiments have shown that it greatly overestimates field retention capacity and underestimates DNAPL penetration depth (Pankow and Cherry 1996, Sect. 13.2.4.2). For instance Poulsen and Kueper (1992, cited in Pankow and Cherry 1996) found that in a sand aquifer the average residual saturation of another chlorinated hydrocarbon, tetrachloroethene (PCE), was only 1.3% if the source was a one-time spill and 0.5% if—as at PGT—the source was a repeated ("drip") spill. These revisions to retention capacity would reduce the effective retention volume of a 10x10x33 ft column to 37 to 96 gallons. That is less than the spilled TCE volume according to Shepherd; thus with this change alone, his method predicts TCE DNAPL migration to the ground-water table at the dirt pile.

Moreover, the use of a 10 ft by 10 ft affected area at the dirt pile is unfounded and seems much too large. This area is not the lateral limits of the path of descending DNAPL, which might be as large or larger due to soil heterogeneity. Rather, 100 ft^2 represents the average area which is actually occupied by TCE DNAPL in a horizontal slice of the vadose zone. The figure seems too high both in an absolute sense and because releases occurred periodically to the same small area, likely repeatedly following the same pathways of modest total cross-section downward.

Pankow and Cherry (1996, pg. 62) conclude that when using the method employed by Shepherd, "depth predictions [of DNAPL penetration] are commonly so unreliable that they are misleading or even useless" (Pankow and Cherry 1996, pg. 62).

• Shepherd claims that the joint introduction of methanol and TCE in the spilled DNAPL enhances degradation of DNAPL. This is most unlikely. Microbial life is not expected within DNAPL due to toxicity of its constituents. Biodegradation is expected, however, where DNAPL dissolves into water or sorbs to soil particles. In these situations, removed from the DNAPL itself, methanol undoubtedly does accelerate TCE breakdown. Within the DNAPL fluid, the presence of methanol is not expected to aid in removal.

• Finally, a Pankow and Cherry (1996, pp.62-63) rule-of-thumb for DNAPL penetration places PGT firmly within the class of sites which create submerged sources:

"As a general rule, we propose that at sites where the water table exists at depths of a few tens of meters or less, and where there are no geologic strata with exceptional capability for impeding DNAPL penetration, a solvent DNAPL release of a few tens of liters at a single location should be considered capable of permitting DNAPL to enter the groundwater zone...[R]epeated small releases at precisely the same location can also produce deep penetration. Indeed we note that significant accumulation of DNAPL below the water table can occur at sites as a result of storage and handling activities where only small amounts of solvent are released at any single location, but the releases are repeated."

In summary, Shepherd underestimates total TCE volume entering the soils at PGT—a more reasonable value is at least several times larger than the Shepherd estimate. He also underestimates the depth of penetration of DNAPL—a more reasonable conclusion is penetration into the saturated zone beneath the water table.

3. SOURCES AND PATHWAYS OF GROUND-WATER CONTAMINATION

Shepherd believes that TCE in the ground water beneath PGT does not make its way to MTHD. He proposes other sources to explain observed TCE contamination; I respond to this opinion in Section 3.1. I then examine the fate of PGT TCE in three sections which consider shallow ground-water flow (Section 3.2), bedrock ground-water flow (Section 3.3) and the TCE plumes (Section 3.4) at the Sites.

It is unclear whether Shepherd believes that TCE in the bedrock ground water beneath PGT makes its way to RHMW. I address this issue in Section 3.5.

3.1 Suggested Non-PGT Sources of TCE at the MTHD Site

Shepherd objects that several potential source areas other than PGT were inadequately characterized by Sites investigations. He directs attention to the Montgomery Township Shopping Plaza (MTSP), Princeton Chemical Research (PCR), and Polycel properties, presumably because all are located north of PGT in areas which could contribute TCE to the MTHD plume if these entities were sources. He apparently does not believe that any TCE within MTHD arrived via the PGT property. He also describes new results from CRA's field investigation at PCR (CRA May 2000). That study was conducted to gather evidence of TCE releases at one of these potential sources, and thus to advance his theory of multiple plumes at the Sites. In this section I discuss the likelihood of TCE releases from PCR, Polycel and MTSP, and the impact any such releases would have on my opinions concerning the contribution of PGT to the MTHD TCE plume.

3.1.1 Montgomery Township Shopping Plaza

The only suspected locations of releases of any type at MTSP are the two septic systems. My understanding is that over time there were four tanks at MTSP: three septic tanks and a grease trap tank. Initially the entire shopping plaza was served by, in series, a grease trap, one septic tank, and a north-south oriented septic field, all located in the grassy area west of the south building of the plaza. This septic system was immediately west of the former Buxton's Restaurant (currently Friendly's Restaurant) (WCC 1988, Plate 3.1; {vol. 2, pg. 44}; pers. comm. C. Searfoss 6/23/00). Repairs to the septic system, of an uncertain nature, were performed in 1978.[29] In 1979 a new employee at Buxton's began pouring Drainz into a floor drain (see below). On May 23, 1980 the Township ordered MTSP to cease using Drainz, thoroughly clean the septic tank, and re-test the incoming effluent (JACA 1984, pg. A-7). At some time after 1980 the shopping plaza upgraded its septic system (pers. comm. C. Searfoss 6/23/00). The original tank and leach field probably were abandoned; the shopping center septic drain line was extended north to two new tanks installed in series in the landscaped strip immediately adjacent to Rt. 206 and west of the current free-standing bank building. These fed a new septic field aligned north-south beneath the landscaped strip. (WCC 1988, Plate 3-1; DRAI 1993a, pg. 1, Fig. 2; Environ 1993a, pg. 20; pers. comm. C. Searfoss 6/23/00).[30]

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[29] Documents authored by Mike Silverman and cited by Environ (3/2000) may clarify the 1978 repairs; they have been requested.
[30] According to Mr. Searfoss the dates and other details of the MTHD septic system history may be determined by consulting Township of Montgomery Health Department files. Mr. Searfoss is retired and did not refer to those files during our conversation.

In February 1980 two samples were obtained from the MTSP septic system by T. Wishart of NJDEP. Specific sampling locations are not specified, but if the preceding chronology is correct then these were likely from the grease trap tank and original septic tank.[31] The sample from one of the tanks ("Septic #2") contained several chlorinated volatile hydrocarbons including 15000 ug/kg 1,1,1-trichloroethane (TCA), 8800 ug/kg 1,1-dichloroethane (11DCA), 290 ug/kg 1,1-dichloroethene (11DCE), and 12500 ug/kg methylene chloride (JACA 1984, pg. 4-7, Table D-4; NJDOH 4/9/80).[32] TCE was not detected. The septic system cleaning product Drainz had been poured into the floor drain at Buxton's at a rate of one 12-16 ounce can of Drainz per week for the year preceding May 23, 1980 (Searfoss 1996, pp. 51-52; Twp. Montgomery Health Dept. 1980f; JACA 1984, pp. 2-15, 4-7; pers. comm. Searfoss 6/23/00). Drainz is described from a Princeton Testing Laboratory analysis as containing TCA, methylene chloride, and aliphatic hydrocarbons (probably petroleum distillates) (Twp. Montgomery Health Dept. 1980f). A 1979 analysis of Drainz also is available at Environ (1993a, App. G) which indicates the presence of a relatively minor fraction (0.14%) of TCE in the Super, but not the Regular, strength formulation of Drainz at that time.

A June 1987 sample from Friendly's Restaurant septic system contained no chlorinated VOC's (WCC 1988, Plate 3.1, Table 5-12, App. F). Given its SW location, it seems that this sample was collected from a non-functioning component of the original septic system.

In early 1992 MTSP connected to the municipal sewer and its septic system was abandoned (Environ 1992a, pg. 21). In December 1992 six soil samples were collected from the vicinity of the two NW abandoned septic tanks and septic field. One sample consisted of a 0.1 ft thick black sludge layer found at a depth of 14 ft bgs and contained 25000 ug/kg PCE, 110 ug/kg TCE, 12 ug/kg trans-1,2-DCE, and other compounds (DRAI 1993a, Table 1; Environ 1993a, pg. 22). As discussed in Environ (1993a) and Chirlin (2000, Sect. 2.3.2.5) this sample apparently was collected from the bottom inside surface of one of the abandoned tanks.

- The septic tank or grease trap which contained TCA and its degradation products—but not TCE—probably was adjacent to Buxton's. But regardless of the true location, the sample analysis implies that this tank and associated septic field did not contribute TCE to the ground water at MTSP in 1980. Furthermore, release of Drainz at an MTSP septic tank in the year preceding May 23, 1980 would have been too late to affect the private wells of MTHD, at least when they were first sampled in November 1979.

- Whether or not it is tank #2 which contained TCA, the SW septic tank may be exonerated of contributions to the MTHD plume. Shallow ground water beneath the tank likely flows toward the north to northwest (Section 2.4.2). Deeper ground water, likely flowing to the north to northeast, yields consistently clean ground-water samples at MW-16 and MW-16D.

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[31] According to {vol. 2, pg. 46} citing Searfoss testimony, the septic tank receiving Drainz and sampled in 1980 was indeed the SW tank near to the restaurant. I have been unable to confirm this from Searfoss testimony I have seen.

[32] Environ (June 2000, pg. 26) states that the lab sheet for this result is not available. I have a copy with Bates # RAV1565. The concentrations are truncated at the right edge of the page, but the chemical names are legible.

- The black sludge sample from one of the abandoned NW septic tanks did contain some TCE and its degradation product DCE. This suggests that some dissolved TCE was released to the associated NW septic field at some time prior to 1992. However, at this location too, shallow ground-water flow is expected to be away from MTHD, here toward the north to northwest. Higher head in P-18I than in shallower MW-18 (in both available data sets) is characteristic of a discharge zone; this is consistent with shallow flow toward the nearby discharge boundary at the unnamed drainage at Village Shopper.[33] The upward hydraulic gradient also implies that dissolved contamination released at this location would not descend into the bedrock aquifer. Finally, if the chronology is correct and the NW septic system was installed in the early 1980s, then any releases at this location would have been too recent to be the cause of observed early contamination at MTHD.

- The ratio of PCE to TCE in the black sludge sample implies that PCE was the main (and perhaps only) original contaminant. Therefore any consequent ground-water contamination is expected to consist predominantly of PCE. The plumes detected at MTSP and MTHD have little to no PCE in comparison to TCE. Therefore the evidence argues against a detectable contribution of TCE to MTHD ground water by releases at MTSP, if any.

- Finally, the only known user of PCE at MTHD is a dry-cleaning establishment which began onsite cleaning operations in 1989; prior to that time the store only provided drop-off/pick-up (Environ 1993a, pg. 23). Although this could explain the PCE in the 1992 septic tank sludge, it cannot be related to PCE or its degradation products observed at MTHD during the period of interest prior to 1989.

In summary, environmental data indicate that the SW septic system at MTSP (next to Friendly's Restaurant) was not a source of TCE to the soils or ground water. Furthermore if the MTSP septic system chronology is correct then the NW septic system was installed too recently to be relevant to the MTHD plume (at least when the plume was first discovered).

3.1.2 Princeton Chemical Research

The 1377 Rt. 206 building which housed PCR until approximately Sept. 1978 has been the subject of several environmental investigations. Most recently CRA {May 2000} revisited facility disposal structure issues (see also LAN 1997), installed wells, and collected shallow soil and ground water samples at PCR. Three septic fields, an infiltration trench, two underground storage tanks, and a tank farm have been identified at the property. A chemical storage area and drum storage area also are mentioned in an NJDEP site inspection.

A purported waste spray irrigation area to the southeast of PCR is of questionable identity, function and ownership. JACA (1984, pg. 2-6) cites "an area reportedly used for

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[33] The decline in head from P-18I to MW-18 observed in both August 1992 and August 1993 suggests that these wells are within a discharge area. If so, that discharge likely is flowing to the north-northwest toward the unnamed tributary at Village Shopper. However, horizontal separation of the two wells could compromise this result, and there are discrepancies in mapped placement of the wells. A field check is desirable.

spray waste irrigation". A white rectangular area appears on aerial photos and has been identified with the "spray irrigation area" (Figure 3.3; Geraghty Miller 1988a, pg. 7, Fig. 4). A consultant to the current property owner claims that the area is not within the PCR property (a March 1974 aerial photo and a tax map appear to corroborate this claim) and that the white appearance may be due to scarification or possibly settling of water related to the shopping center expansion (LAN Associates 1997, para. 4).

One PCR septic tank sampled in February 1980 contained 95 ug/kg TCE; a different tank sampled in April 1980 contained no TCE (ND[25] ug/kg) (JACA 1984, pg. 2-11, Table D-4; TMHD 1980d). The SW septic tank was sampled in June 1987 and contained chloroform (13 ug/l), bromodichloromethane (2j ug/l), methylene chloride (5.4 ug/l), toluene (8.4 ug/l) and acetone (23 ug/l), and no TCE (WCC 1988, App. G, Plate 3.1). All three septic tanks were sampled in 1999: benzene (2690 ug/kg), chlorobenzene (158000 ug/kg), 1,4-dichlorobenzene (up to 24100 ug/kg), toluene (up to 2410 ug/kg) and the PCB Aroclor 1248 were detected, and TCE was not found (LAN 1999; LAN 1997 Att. 2,3,4).

Soil sampling at PCR in 1982-83 detected xylenes (up to 10400 ug/kg), toluene (up to 33 ug/kg), 1,2,3-trichlorobenzene (980 ug/kg), methylene chloride (735 ug/kg), PCE (100 ug/kg), and PCBs in one or more samples (NJDEP 1986, App. B-2; LAN 1996, Table 9.2). TCE was not detected.

The depth to ground water at PCR is variously reported. Shallow ground water during the May 2000 investigation was encountered at 8 to 20 ft bgs {May 2000, Table 2.4}. In (apparently) 1988 Hart Assoc. (1989, pg. 2) did not encounter ground water in three borings to approximately 30 ft bgs (10 ft into bedrock).[34]

CRA found that the shallow ground water at PCR contains concentrations of TCE up to 47 ug/l and PCE up to 19 ug/l {May 2000, Tables 3.2 and 3.3}. Contrary to {May 2000, pg. 15}, there is no apparent pattern of increase or decrease in concentrations across the property. Shepherd claims that the observed concentrations may be extrapolated backwards in time to higher values {May 2000, pg. 16}. But there is no scientific basis for such a calculation unless one also links the contamination to a particular plume which has historical data. That linkage, of course, is the subject of the debate and should not be made *a priori.*

The two bedrock wells at PCR have consistently contained TCE. PCR-P1, located south-central of the building, detected 67 ug/l TCE in its only sample (1981)[35]; PCR-P2 has contained 125-502 ug/l TCE (1980-1987). PCR-P2 also has contained up to 14.5 ug/l PCE, 19 ug/l DCE, 10.7 ug/l TCA, 58.8 ug/l 11DCA, 1200 ug/l hexachlorobutadiene

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[34] LAN (1996, pg. 13) claims that bedrock well PCR-P2 is 10"-diameter, cased to 40 ft bgs, open to 500 ft bgs, yielded 205 gpm, and flowed at the surface when installed in 1962. However, I am dubious of this report because the described well perfectly matches a drilled and immediately abandoned supply well at the Rocky Hill wellfield (Rogers and NUS 1984, App. E). Furthermore, elsewhere PCR-P2 is reported to be 300 ft deep (JACA 1984, pg. 4-9). Artesian conditions at PCR would be significant if PCR therefore lay within a discharge zone where dissolved contamination could not descend into the bedrock zone.

[35] Some samples assigned to PCR-P2 are ambiguously labeled and may have been collected from PCR-P1.

(its solubility in water is approximately 2000 to 3000 ug/l), 611 ug/l α,α,α-trifluorotoluene, 163 ug/l carbon tetrachloride, 50 ug/l methylene chloride, and 40 ug/l Freon 113.

- The February 1980 detection of TCE in one of the septic tanks suggests that some dissolved TCE was used and released to the environment at PCR, although it is possible that the TCE in the tank was a degradation product of PCE. The duration, magnitude, fate and specific location (which tank?) of any such release are unknown.

- As a whole, and contrary to the opinion expressed by CRA {May 2000, pg. 15}, the field data do not confirm that PCR is a detectable source of TCE to the ground water. The observed shallow ground-water concentrations of TCE and cDCE are too small (all less than 50 ug/l) to alone be diagnostic of an onsite source. The four stations on the upgradient (south) side of the property—and the relatively shallow Polycel bedrock well further upgradient—have chlorinated volatile organic concentrations (TCE and others) which are very similar to the five stations on the downgradient side of PCR.[36] The relatively high concentration ratio of PCE to TCE (typically 20%-40%) in the shallow PCR wells is not characteristic of the observed shallow or deep plume elsewhere at the Sites (although it is seen in some of the Polycel bedrock well samples). No meaningful pattern of increase across the property is evident.

- Shepherd's requires that "confirmatory soil data...[are] needed to validate the source" {vol. 2, pg. 51}. CRA performed soil sampling at PCR and none of the soil samples within the vadose zone contained TCE. Therefore according to Shepherd's criterion PCR is not validated as a source of TCE at the Sites.

- It is clear that PCR did release hazardous substances other than TCE to the soils and that these releases made their way to the ground water at the property. An NJDEP inspection in August 1973 found that PCR
    "had discharged pollutants onto the ground at numerous locations on the site, including areas near the north, east, and south side of PCR's production building. In addition, the soils surrounding several storage tanks at the facility were also contaminated with materials spilled from the tanks. The representative also observed spillages on the soil in the vicinity of the drum storage area and the chemical storage area" (NJDEP 1986, para. 4).
  In 1986 NJDEP issued an Administrative Order related to these releases. Xylenes and PCBs have been found in both soil and ground water on the north side of the building, and are linked to PCR activities.

- It is reasonable to speculate that hexachlorobutadiene, a rubber solvent, was used at PCR where 1400 lbs. of polybutadiene (a synthetic rubber) was handled daily (as of 1973, NJDEP 1996, App. A). If the solvent was used, then it is possible that PCR is responsible for the 1200 ug/l hexachlorobutadiene detected in ground water at PCR-P2.[37]

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[36] The CRA study established that shallow ground water flows north to northwest beneath the PCR property and is contaminated with dissolved PCE, TCE, cis-1,2-dichloroethene (cDCE), 1,1-dichloroethane (11DCA) and xylenes, among other compounds.

[37] Only one sample detected hexachlorobutadiene in PCR-P2; validation is desirable.

- But the releases of these other compounds by PCR does not show that PCR contributed TCE to the ground water or to the observed MTHD TCE plume.

3.1.3 Polycel

The former Polycel plant occupied land much of which currently lies beneath the north building at MTSP. It is known that the facility extruded plastics; nothing else has been reported concerning its products, processes or wastes.

A February 1980 septic tank sample detected TCE (31 ug/kg), 12DCE (3.6 ug/kg), PCE (16 ug/kg), and 11DCA (6 ug/kg) (JACA 1984, Table D-4). The location of the septic tank and septic field are uncertain. A liquid sample from a pipe—later said to be an electrical conduit—north of the former building contained 1,4-dichlorobenzene (182 ug/l) and hexachlorobutadiene (1076 ug/l).

Soil samples at seven locations within Polycel during the RI contained no VOCs.

Topography and proximity to PCR suggest that shallow ground-water flow at and west of the Polycel building travels toward the north-northwest (Figure 3.1).

The February 1980 detection of TCE in one of the septic tanks suggests that some dissolved TCE was used and released to the environment at Polycel, although it is possible that the TCE in the tank was a degradation product of PCE. The duration, magnitude, fate and specific location of this release are unknown.

The shallow ground-water quality at Polycel has not been sampled. Bedrock water quality is characterized by the 150-ft deep Polycel well which on its five sampling dates between 1980-1983 contained up to 98 ug/l TCE, 16.5 ug/l PCE, 4.2 ug/l TCA, and 30 ug/l 11DCA, and 3 ug/l α,α,α-trifluorotoluene (4/12/82), 13 ug/l hex-chromium (4/12/82), and 0.80 ug/l PCB-Aroclor 1248 (5/17/83).[38]

- Absent dense sampling, one can always speculate about unknown releases on a property, and Polycel is no exception. The septic system contained several VOCs at low concentrations. However, the available data do not imply that Polycel was a detectable source of TCE to the MTHD plume, and the site-wide configuration of TCE and related compounds within the ground water can be otherwise explained.

3.2 Shallow Ground-water Flow

The direction and horizontal range of shallow ground-water flow is of interest at the Sites in part because it provides a mechanism for contaminant transport in a cross-strike (north to northwest) direction. The direction of shallow flow is dictated by the shape of the shallow piezometric surface and, as discussed below, is generally toward the north to north-northwest over much of the area north of PGT.

- The range of shallow flow before it descends fully into bedrock fractures is less easily discerned and is expected to vary from place to place. As discussed in Section 2.4.3, it is clear that shallow flow at PGT persists for at least the distance from the dirt pile to highly contaminated PGT-3 (400+ ft). Shepherd indicates persistence of shallow flow for at least 2000 to 3000 ft within his north plume {vol. 2, Figs. 3.8, 3.9}. DRAI (1992a,

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[38] Most analytes were not quantitated in every sample.

pg. 11) implies that shallow zone contamination could travel at least as far as from PCR to MW-5S, a distance of approximately 1500 ft.

There is agreement that the weathered materials comprise a high-porosity, site-wide blanket which ultimately recharges the underlying bedrock fractures. The weathered zone is generally characterized as containing numerous minute and poorly integrated fractures which generate lower permeability and greater storage than is found in the bedrock, and "updip extensions of the major bedding fractures in the weathered zone provide dominant pathways for downdip drainage across the weathered zone" (Michalski and Britton 1997, pg. 319).[39]

The Michalski model says nothing concerning lateral transport within the weathered materials. However, persistent lateral transport within the shallow zone clearly occurs at PGT and therefore should be anticipated elsewhere at the Sites. It may be that major bedrock fractures are widely spaced in some areas of the Sites, thus promoting lateral flow within the shallow zone. Slug tests at shallow and deep wells revealed little difference in hydraulic conductivity (WCC 1988, Table 5-4).

The direction of shallow ground-water flow at the Sites is determined by first constructing a piezometric surface contour map. Flow is then interpreted to proceed perpendicularly from higher to lower contours. Shallow ground-water elevation measurements are the most reliable source of data for constructing such a map. Where measurements are spatially sparse or absent, topographic information may be used to infer the shape of the piezometric surface, although accuracy of inferred contours and flow directions is reduced. At the Sites shallow wells are not available in several areas of interest and therefore analysts have relied on topographic cues to fill in the gaps. Before discussing my interpretation of the shallow piezometric surface, I present two comments on the maps prepared by Shepherd.

- I disagree with Shepherd's rendition of the shallow ground-water piezometric surface at the Sites. He claims that lateral flow follows the top of rock and topographic structures to the north and east {vol. 2, pg. A-14}. However, in areas of importance to this report, the topography rises to the east (peaking east of Merritt Lane) and falls to the north and west (WCC 1988, Plate 3.1; Figure 3.3). Where shallow water level data have been collected at sufficient density to delineate flow direction (at PGT and PCR), shallow flow has been found to have a western component, in a direction opposite to that of Shepherd's interpreted directions in {vol. 2, Figs. A-8 through A-10} (see also Environ 2000, para. C).

- Shepherd errs in interpolation of shallow ground-water piezometric contours due to omission of data points. The shallow ground-water piezometric contours of {vol. 2., Figs. A-8, A-9 and A-10} are incorrect in the vicinity of Route 206 north of MW-18. This is due to omission of data for MW-14S in Fig. A-9 (it was 60.16 ft NGVD) and presumed similar conditions on the other two dates; to lack of recognition of approximate water levels at MW-21 nest (P-21S water level is approximately 9 ft

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[39] The Michalski (1990) conceptual model described in Chirlin (2000) and elaborated upon by Michalski and Britton (1997) has recently been found to be applicable and to inform data interpretation at additional Passaic Fm. study areas in Hopewell, NJ (Morin, Carleton and Piorier 1997), near Somerville, NJ (Michalski and Britton 1997), and in Lansdale, PA (Morin, Senior and Decker 2000).

lower than at MW-21I per CDM (1993, Table 4-1)—this apparently is a discharge zone—and data is available for MW-21I for August 1993); and to disregard of the topographic mimicry rule (which he previously invoked) where land surface declines toward the unnamed drainage at Village Shopper.

In Figure 3.1 I present a shallow ground water piezometric surface map which is consistent with the Sites data. The piezometric contours reflect the water elevation data, topography, drainage to the unnamed tributary north of Village Shopper, and locally depressed water elevation near to RHMW. For reference, I include a topographic map as Figure 3.3.

For comparison with {vol. 2, Fig. 3.5}, in Figure 3.1 I have sketched in the implied divide between shallow waters which flow toward RHMW and those which do not.[40] Unlike {vol. 2, Fig. 3.5}, the interpreted divide passes through PGT.

Discharge to the MTSP SW septic field prior to its abandonment in the early 1980s (if the chronology is correct) likely would have altered the shallow piezometric surface from that of Figure 3.1. Mounding beneath the SW field would tend to inhibit shallow flow from PGT toward west-northwest through northwest, and thus may have diverted the PGT TCE plume away from the vicinity of MW-16 and MW-16D.

3.3 Bedrock Ground-water Flow

The Michalski model implies that bedrock ground-water flow at the Sites moves preferentially along the strike of bedding planes, which is to the northeast or southwest, and provides for leaky cross-strike flow. Contrary to {vol. 2, pp. 17, A-10}, there is significant cross-strike migration of ground water at the Sites. Shepherd invokes significant cross-strike flow (to the north and to the east) in order to explain observed features of the Sites {vol. 2, pp. 28, A-21}. This is consistent with the observation by Houghton (1990,-cited in Environ [1993a, pg. 11]) that aquitard strata of the Passaic Formation are inherently leaky.

- *The Sycamore Road Test.* At the Sites there is significant migration of ground water and contamination in a cross-strike direction (Chirlin 2000, Sect. 4.2.5.4). Unless there are other as yet undiscovered sources, there is no other way to explain observed TCE contamination in bedrock wells north of PCR to Sycamore Rd. including P-21S, 29002-40 through 29002-43, and 29003-13 through 29003-15. A viable theory of Sites hydrogeology must accommodate these data. (Shepherd does not address this matter). Either contaminated flow moves north within weathered shallow materials for more than 1000 ft (from at least PCR to 29003-15) and leaks downward along the route, or contaminated flow moves north through cross-strike fractures within the competent bedrock, or both. Concentrations of TCE conveyed cross-strike reach 120 ug/l at P-21S (not a shallow well, it is screened from 75-100 ft bgs) and 35 to 61 ug/l at 29002-40 through 29002-43. One must conclude that cross-strike migration (however accomplished) is a significant transport mechanism of dissolved TCE at the Sites.

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[40] Ground-water which descends into the bedrock is not subject to the shallow divide; therefore the zone of capture of RHMW is not defined by the divide.

• *The MW-17/TW-2 Test.* A viable theory of Sites hydrogeology also must explain the observed contamination at wells MW-17 and TW-2. (Shepherd does not discuss the matter). As described in Chirlin (2000, Sect. 4.2.5.4) both wells contained TCE in all samples with maxima of 300 ug/l and 170 ug/l, respectively. If the wells are not contaminated by an unknown source, then they must reflect contamination which has migrated north—and hence cross-strike—from PGT. There is no evidence for a TCE release from the SW MTSP septic system (Sect. 3.1.1) and along-strike wells MW-16 and MW-16D detected little or no TCE. Polycel and PCR are located too far north to contaminate MW-17 or TW-2.

• *Along-strike flow at PCR.* Shepherd interprets along-strike flow within the bedrock beneath PCR to be toward the northeast. However, that is not necessarily the case; along-strike flow can also be to the southwest As discussed below, the Shepherd bedrock piezometric maps are flawed. Figure 3.2 indicates that in the vicinity of PCR the piezometric surface projected along strike (northeast-southwest) is nearly flat and bedrock ground water at PCR may drain along-strike to the southwest toward the unnamed tributary at Village Shopper.

Comments on Shepherd's Bedrock Piezometric Maps

Most investigators have constructed piezometric maps for the bedrock unit at the Sites. Shepherd offers three such maps {vol. 2, Figs. A-5 through A-7}. His maps are unrealistic in several respects, due in part to use of only a subset of the available data (he uses only wells screened between elevations +100 and −10 ft NGVD {vol. 2, pg. A-9}). Although some vertical variation in head is expected within the bedrock unit, it is generally small except near to pumping wells or discharge features. The analyst should refer to all bedrock well water level measurements, and the interpretation should be informed by these and other obvious clues, such as the location of pumping well RHMW and observed water levels on other dates for wells not monitored on the mapping date.

• Shepherd does not use all data to inform his interpolated bedrock piezometric contours. He presents incorrect and misleading figures which are completely oblivious to the effects of RHMW. One map even has drawdown centered about a monitoring well (MW-20D) {vol. 2, Fig. A-6}. He omits water elevation data for MW-1D. He does not use streambed elevation information along the unnamed tributary, even though he claims that the stream is a drainage feature. The figures are not valid and should not be used.

• Shepherd agrees that there is a divide within the bedrock ground-water flow system in the vicinity of PGT. However, contrary to {vol. 2, pp. A-9 to A-10}, this divide is caused principally by pumpage at RHMW and separates flow destined to RHMW from that proceeding to the north to northeast.[41] Shepherd draws this divide as a straight

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[41] In the absence of RHMW there would be a broad curvature in the bedrock piezometric contours due to divergence to drains on three sides (unnamed tributary near Village Shopper, Beden Brook, unnamed tributary SE of RHMW, and Millstone River). There would be no meaningful placement for a divide because a divide is not defined uniquely for a broadly curving shape. (Alternatively, there could be several divides, separating flow into sectors destined for each draining water body). Reference to WCC (1988, Fig. 5-4)—static water elevations in deep wells after 14 hr without RHMW pumpage—can be misleading. Sharpness of the bend in contours is driven by water levels at MW-7D in conjunction with MW-10D, MW-9D, and RHMW; the latter three likely were still depressed several feet due to chronic drawdown of, and slow recharge from,

line through MTSP, passing approximately through MW-16, MW-5 and MW-2 {vol. 2, Fig. 3.6}. There is no particular justification for this placement or linearity. There is agreement that available data do not fix the position of the divide precisely. But nevertheless in his theory of the origin of TCE observed at PGT he relies on a placement of the divide within MTSP. Therefore I demonstrate a justifiable placement of the divide within PGT in Figure 3.2, using water elevation data for August 11, 1993 (DRAI 1993b, Table IV).

A divide follows a local ridge in the piezometric surface. The divide through PGT in Figure 3.2 is consistent with water elevation data: MW-7D is higher than, and MW-7DD is approximately the same elevation as, MW-16 or MW-16D. (Indeed on most observed dates MW-7D is even higher relative to MW-16). Furthermore, on a different date the single water level measurement at PGT-P1 found it to be approximately equal to PGT-4 (DRAI 1992a, Table II). That suggests that on August 11, 1993 the bedrock piezometric elevation at PGT-P1 was approximately 107.6 ft NGVD, which is high enough to be close to the divide. In addition, this divide placement is approximately aligned with the interpreted overlying divide in the shallow materials (Figure 3.1).

The divide shown in Figure 3.2 is a reasoned example, but is not well-defined by the data. During the period through 1977 or 1982, when RHMW pumpage was 52% greater than during Sites investigations (Chirlin 2000, Sect. 4.2.5.3), the divide may have been displaced to the north or northeast.

Precise placement of the bedrock ground-water flow divide is not important to my opinion. As long as the divide is not to the south of PGT (and no one has disputed this) then at least some portion of the bedrock ground water beneath PGT is captured by RHMW. On the other hand, shallow ground-water flow carries TCE from PGT to the north. It is known that shallow flow proceeds approximately 400 ft southwest across PGT from the dirt pile to PGT-3; a similar migration distance to the north is sufficient to carry TCE half-way across MTSP and beyond even Shepherd's placement of the bedrock divide in {vol. 2, Fig. 3.6} (i.e., beyond capture by RHMW).

- The water elevation values in {vol. 2, Fig. A-6} for August 1993 do not agree with those in DRAI (1993b, Table IV), and no source is cited.

- Shepherd opines that travel times from PGT are too long for PGT to be responsible for contamination observed in MTHD {vol. 2, Sect. 3.4.2, App. B}. However, the water particle velocities used in {vol. 2, Sect. 3.4.2 and App. B} are too small. Flow within the dominant bedrock fractures typical of this setting can move much more quickly than that through porous media because of the low effective porosity of the fractured medium. Furthermore, within MTHD flow through the fractures was accelerated by pumpage of the domestic wells. Finally, each hydraulic conductivity value used to calculate particle velocity incorporates an estimated thickness of the tested zone (e.g., the screen or open hole length for slug tests in WCC [1988, Sect. 5.2.1.3], 20 ft for packer tests in CDM [1993, Sect. 6.3]) which is generally much too high to reflect

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the shallow zone and cross-strike bedrock flow. Indeed it is clear from CDM (1993, Figs. 4-7 and 4-8) that after 14 hours (projected) both MW-9D and MW-10D are still rebounding from RHMW pumpage. Over months of RHMW inactivity the contoured bedrock piezometric surface likely would broaden substantially to the south.

the total width of the tested fracture apertures. As a consequence the calculated hydraulic conductivity is much too low to represent the actual hydraulic conductivity within the fractures.[42] Therefore the use of these hydraulic conductivity estimates causes a substantial underestimate of the particle velocity, and a concomitant substantial overestimate of the travel times through the fractured medium.

3.4 Plumes of TCE Contamination

Shepherd opines that three separate plumes of TCE exist within the Sites, and that these are caused by releases at three or more separate facilities, none being PGT. The plumes, which he calls the north plume, middle plume and south plume, are sketched for two dates (1986-87 and 1998) and two depths (shallow and deep) in {vol. 2, Figs. A-24 through A-27} and described in {vol. 2, Sect. A.3.3 and A.3.4}. Shepherd believes that bedrock plumes at the Sites are created and replenished by contamination released to the shallow materials {vol. 2, pg. 10}. This is accurate, except where DNAPL has descended into the bedrock. The south plume originates at FDI; this is accurate in concept. The middle plume purportedly originates at both Mobil/Collins Auto and the southwest corner of MTSP, and the north plume at Polycel and/or PCR. In Section 3.4.1 I make some comments concerning Shepherd's delineation of a north and middle plume. In Section 3.4.2 I present my interpretation of the TCE distribution at the MTHD.

3.4.1 Comments on the "North" and "Middle" TCE Plumes of Shepherd

Shepherd distinguishes two separate plumes within the MTHD Site at and north of PGT: the middle plume and the north plume. In this section I review my findings concerning the middle plume, describe errors and unjustified assumptions underlying Shepherd's inference of a separate north plume, and point out where the Shepherd plumes are inconsistent with observed water quality data.

Middle Plume. Shepherd's middle plume encompasses PGT. Shepherd draws and interprets the middle plume as if it originates at Mobil/Collins Auto and southwest MTSP. In Section 2.4.1 and 2.4.2 I explain that due to the direction of shallow ground-water flow, any sources at Mobil/Collins Auto and MTSP would not cause the observed contamination at PGT. My interpolation of the shallow piezometric surface (Figure 2.1) also makes this clear. In Section 2.4.2 I review the available evidence concerning MTSP and find nothing to suggest a TCE release anywhere near to PGT. In Section 2.4.2 I also review evidence concerning Mobil/Collins Auto and find no indication of a TCE release at that property. Soil gas samples within Mobil/Collins Auto along the boundary with PGT are clean. Finally, I discuss the extent and migration of the TCE plume from PGT, including its shallow stage, in Sections 2.4.3 and 3.4.2.

North Plume. Shepherd infers that a separate north plume exists at PCR, Polycel and generally northeastward. He refers to four figures {vol. 2, Figures 3.8 through 3.11} as support for the two-plume theory. However, these figures are neither correct representations of the underlying data nor unique interpretations of the data. In the following paragraphs I discuss deficiencies of the figures. Beyond that, I address the issue of the separateness and origin of the north and middle plumes by examining a related question: what is the origin of observed contamination at well MW-4D?

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[42] CDM (1993, pg. 6-5) makes a similar observation. WCC (1988, pg. 5-8) also notes the ambiguity of the aquifer thickness parameter for fractured rock.

Shallow plumes. CRA {vol. 2, Figures 3.8 and 3.9} discriminates multiple shallow plumes of TCE-contaminated ground water. There are two plumes shown in Figure 3.8 and three in Figure 3.9. The plumes are delineated and differentiated by means of interpolated TCE concentration contours, or "isopleths". Contour diagrams generally are understood by scientists to rely upon and interpret the posted data points. Here the posted data are TCE concentrations at wells, such as 650 ug/l at MW-7S. Shepherd makes errors and unjustified assumptions in drawing these shallow plumes.

- The interpreted contours in {vol. 2, Figure 3.8} could not--by any plausible stretch of the imagination--be derived solely from the posted data points for 1986-87. The delineation of two separate shallow plumes from the posted data is not justifiable. This can easily be seen if one traces the posted values onto a blank sheet of paper and then contours the values. The data simply do not imply, or even faintly suggest, a separation into two distinct plumes. The separation merely manifests an independent opinion of the analyst (Shepherd); the data do not provide support for that opinion.

- Moreover, there are only three posted TCE values defining the north plume as interpreted in {vol. 2, Figure 3.8}. One of those values is taken from a well (MW-17) screened entirely within competent bedrock and therefore inappropriate for delineation of Shepherd's "shallow hydrostratigraphic unit".[43] The second is taken from a well (MW-5S) which is represented on the figure as ND (not-detected) but in fact was never sampled because it never contained any water. The only valid data point, MW-3S, is contaminated and therefore cannot serve to discriminate two plumes.

- The same argument applies to the 1998 north and middle plumes of {vol. 2, Figure 3.9} after consideration of additional well P-21S. Like MW-17, P-21S is too deep to represent a "shallow hydrostratigraphic unit" and should not be included in the figure. According to the boring and construction logs P-21S is open to the depth interval of 75-100 ft bgs and competent bedrock begins 59 ft bgs. Furthermore, the piezometric surface at P-21S is approximately 50 ft above the top of the open interval of the well: the shallow ground water interval likely lies substantially above the sampled interval. In any case, P-21 also is both contaminated and inappropriately located to discriminate two separate plumes.

In summary, the delineation of separate shallow north and middle plumes by Shepherd is not grounded in Sites TCE ground-water data.

- The rounded shape of contours of the south plume in {vol. 2, Figure 3.9} is not based on posted data. The interpreted extension of shallow TCE contamination to the southeast represents an opinion unrelated to the water quality data. The posted data very nicely fit a narrow northeast trending plume extending from FDI towards RHMW, as would be expected for flow predominantly along strike.

Deep plumes. Similar to the shallow plumes, {vol. 2, Figures 3.10, 3.11} interpret two or three separate TCE plumes in the deep bedrock. Here too, errors of omission and unjustified assumptions underlie Shepherd's interpreted plumes.

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[43] Indeed, his figures exclude data from essentially identically constructed well MW-16.

- At well MW-7D competent bedrock is logged beginning 31 ft bgs, and the well is open from 42 to 102 ft bgs (WCC Installation Report for MW-7D). Therefore MW-7D is open solely to competent bedrock and water samples from MW-7D characterize the bedrock aquifer. Shepherd agrees that MW-7D is a bedrock monitoring well and even uses MW-7D to exemplify TCE concentration trends in the "deeper competent bedrock zone" and "deep groundwater" {vol. 2, pg. A-23}. Yet Shepherd omits the water quality data for highly contaminated MW-7D from his interpreted TCE plumes in {vol. 2, Figures 3.10 and 3.11}. Inclusion of the 1986-1987 MW-7D data (650 ug/l and 180 ug/l in two samples) in {vol. 2, Figure 3.10} would greatly intensify, widen, and lengthen the interpreted "middle" plume, even to the point of merging the "north" and "middle" plumes on the east side of Montgomery Plaza Shopping Center.[44]

- As mentioned above, P-21S (65 ug/l TCE) should be included in the deep bedrock plume {vol. 2, Fig. 3.11}. Furthermore, IW-1 (21 ug/l TCE) which is posted on the figure, is not properly contoured. When these two corrections are made, the plume will clearly extend due north of PCR.

- Shepherd ignores the detected TCE at MW-2D in {vol. 2, Fig. 3.10}. MW-2D has contained TCE on all six sampling dates from 1986-1998. This should cause the interpreted plume to be extended to the east, as is consistent also with the many earlier, but unrepresented, samples from residences on Cleveland Circle (Figure 3.4).

- More fundamentally, Shepherd's theory of north and middle plumes fails to explain the consistently observed contamination in Cleveland Circle.

- There are 33 results of analyses for MTHD residences during the period of 1986-1987. They are available in the RI and fall within the time interval of his figure, and yet none of them are included in {vol. 2, Fig. 3.10}. If, for instance, Shepherd had included the results for residences along Sycamore Lane between Rt. 206 and Robin Dr., his plume would have extended strongly to the north of PCR.

- By contouring data from only certain dates on which some wells were not sampled, Shepherd fails to represent known features of the Sites TCE plume. For instance, the known contamination at TW-1, PCR-P2 and Polycel are never represented in his figures.

- The contours in {vol. 2, Figures 3.10 and 3.11} are not unique interpretations of the data. In particular, both could be legitimately altered by connecting the north and middle plumes into a single plume which extends northward from the east side of PGT. Shepherd states that clean wells MW-18 and MW-16 define a boundary between his two plumes, but they are both too far west to do so. Again, this can be seen if one traces the posted values onto a blank sheet of paper and then contours the values.

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[44] This assumes only that data is consistently interpreted throughout the figure. Since the observed value of 168 ug/l at MW-3D implies a plume extending laterally some 1600 ft farther to the northeast, then the higher observed values at MW-7D should imply at least a similar lateral extent of contamination from the northeast corner of PGT.

Thus Shepherd's flawed diagrams do not resolve the question of whether a second plume—or more pointedly a second source—of TCE exists north of PGT.

3.4.2 Plumes of TCE at the Sites

In fact, available Sites data do not resolve to scientific certainty whether two plumes exist, or in other words, whether Polycel and/or PCR contribute to the TCE detected in MTHD. The PGT single-source theory is consistent with the Sites data; a source at Polycel or PCR is not required to explain observed contamination at MTHD. To illustrate this I have prepared diagrams of the TCE plume emanating from PGT which are consistent with all relevant Sites data. Figure 3.4 provides a diagram of the shallow portion of the plume and Figure 3.5 a diagram for the plume within competent bedrock. I discuss each of these diagrams below. But as stated previously, even if Polycel and PCR are sources of TCE to MTHD, contamination at MW-17 and TW-2 data does show that PGT has contributed to the MTHD plume.

The Shallow TCE Plume. There is without question a plume of TCE-contaminated ground water within the shallow materials at PGT. As discussed in Section 2.4.3, this plume originates in the northeast portion of PGT, principally at the dirt pile with additional contributions likely in the past from the overflow pit and original septic field. It radiates outward in accordance with its location at a local high in the shallow piezometric surface (Figures 2.1, 3.1).

Based on observed concentrations at PGT-1, PGT-3 and PGT-4, some TCE from the dirt pile spill residual and from likely submerged DNAPL migrates to the southwest across PGT. (Historically, the septic systems also contributed). The interpreted piezometric surface for the shallow zone (Figures 2.1, 3.1) implies that TCE also migrates to the south across PGT where no monitoring wells were installed. Dissolved TCE within the shallow materials continues spreading outward to the west through south (Figure 3.3). An inferred saddle in the piezometric surface splits the plume southwest of PGT (Section 2.4.3).[45]

To the west the extent of the shallow plume is not defined by water quality data. There are no shallow monitoring wells along this path; however, TCE contamination at the Mobil well in 1983 likely reflects this portion of the PGT plume.[46] Flow eventually infiltrates the fractured bedrock system.

On the east side of the saddle, shallow flow conveys TCE from PGT further into the piezometric depression caused by long-term pumpage of RHMW and eventually infiltrates the fractured bedrock system.

Based on observed TCE at PGT-2 and MW-7S and interpreted piezometric contours for the shallow zone, dissolved TCE from the dirt pile spills also migrates northward to

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[45] The placement of the saddle is approximate. The interpreted split in the plume may instead be an artifact of an unreliable well. Several other possible reasons for absence of TCE at the Town & Country Animal Hospital well are discussed in Chirlin (2000, Sect. 4.2.5.5). It is also possible that contaminated shallow ground waters from PGT descend into the bedrock before reaching the Town & Country well and then move away from the well toward RHMW.

[46] The location of the Mobil well is uncertain. Wells are typically adjacent to structures; this one could then be next to either of the main buildings and therefore could be closer to PGT than the figures indicate.

northwestward from PGT. (Again, historically the septic systems also contributed). The TCE moves into MTSP beneath the pavement and east building.

Wells MW-16 (ND) and MW-16D (up to 7 ug/l TCE) within MTSP have detected little or no TCE since the first samples in 1987 and 1992, respectively. The wells are approximately 400-450 feet northwest from the dirt pile. That is about the same distance as the observed southwest shallow migration of TCE within the PGT property. These monitoring wells are not open to the shallow materials. The shallower MW-16 is open from 57-82 ft bgs and depth to water at that location is approximately 20 ft; any shallow plume would lie above the monitoring well openings. However, it is possible that TCE does not proceed northwest from the spill area toward MW-16. If that is so, it may simply be due to a distribution of TCE DNAPL and vapor which does not affect the subsurface upgradient of MW-16. That area, inferred from Figures 2.1, is on the west side of the main septic field and north of the overflow pit. Both of these features also have added TCE-free water or leachate to the shallow flow subsequent to October 1980. Finally, the PGT TCE plume may not intersect with MW-16 due to heterogeneity in horizontal or vertical conductivity of the intervening shallow materials.

As indicated by Figures 2.1, 3.1, and 3.3, TCE from the PGT spill also migrates to the north. The shallow plume extends beneath the pavement of MTSP. Descent into bedrock is inhibited due to the impervious cover of the MTSP which prevents rainfall infiltration. The plume in Figure 3.3 is aligned with the piezometric surface of Figure 3.1, which implies that shallow flow curves to the northwest toward PCR. I have indicated persistence of shallow flow to Sycamore Rd. where several residential wells are contaminated; however, the plume may actually descend earlier and migrate cross-strike through bedrock fractures as implied by Figure 3.2.

The north leg of the shallow plume is interpreted to curve west of wells MW-17 and TW-2. In some combination of shallow flow, down-dip flow within major fractures, and cross-strike flow through aquitards, contamination from this PGT plume passes through the area north of the east building at MTSP including wells MW-17 and TW-2. As discussed in Section 3.3, no source other than PGT has been identified or suggested which could have contaminated these monitoring wells.

The source of recently observed shallow ground-water contamination at PCR, including TCE up to 47 ug/l and PCE up to 19 ug/l, remains uncertain (Section 3.1.2). The relatively high concentration ratio of PCE to TCE (typically 20%-40%) is not characteristic of the observed shallow or deep plume elsewhere at the Sites, although it is seen in some of the Polycel bedrock well samples. If both chemicals originate from the same source, then the source is likely not PGT, and the impact of this relatively high PCE release (wherever it may be) apparently has not spread to other sampled areas.

Alternatively, the sources of the two chemicals differ. In that case the TCE may be derived from PGT, with persistently shallow migration across MTSP, promoted by the impermeable pavement cover, leading to the shallow plume shown in Figure 3.4.

The Deep TCE Plume. The deep TCE plume at the Sites is interpreted in Figure 3.5.[47] The diagram reflects descent of ground water and contamination along the course of the

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[47] Figure 3.5 may be compared to {vol. 2, Fig. A-6} which is also based on August 1993 water level data.

shallow plume of Figure 3.4 and subsequent migration within the bedrock along bedding planes (to the northeast in most areas) and through cross-strike fractures (to the north in most areas) as promoted by the bedrock piezometric surface (Figure 3.2).

A portion of the shallow contamination on the west side of PGT descends into bedrock. There is negligible along-strike hydraulic gradient within the bedrock in this vicinity because piezometric lines parallel strike (Figure 3.2); where flow descends it will tend to move cross-strike to the southeast toward RHMW, depending on the position of the divide (see Section 3.3).

Based on the absence of TCE at bedrock well MW-5D which is approximately along-strike from PGT, the north-trending shallow plume from PGT may not descend to bedrock and spread to the northeast in the immediate vicinity of PGT, but rather at a more northerly point along its path within MTSP. This may be due to the inhibition of recharge by MTSP pavement, by a small along-strike hydraulic gradient along the early path of the plume (Figure 3.2), or by absence of conductive updip bedding plane fractures in the interval. Section 3.2 discusses evidence of persistent shallow migration at the Sites. The pre-1980 aggregate pumpage by MTHD, which is not reflected in Figure 3.1, also likely strengthened the along-strike hydraulic gradient where the plume approached the north end of MTSP, promoting descent and northeast spreading of the shallow contamination in that vicinity.

On the other hand, a portion of the shallow contamination on the north side of PGT may indeed descend into the bedrock and migrate generally along-strike to Cleveland Circle, but not be detected at MW-5D. MW-5D contained no detectable TCE in four samples between 1986-1992, and Shepherd argues that these clean samples imply that TCE at PGT does not migrate to Cleveland Circle. However, one clean well is not conclusive evidence of the absence of a plume. Even in the midst of the MTHD plume there are wells where little or no TCE was detected in repeated samplings (e.g., well 29002-16: ND in all 6 samples; 29002-01: ND in 4 of 5 samples; 23001-29: ND in all 2 samples; 23001-21: ND in 3 samples, 1 ug/l in 2 samples). There are various factors which could be responsible for a clean well such as MW-5D within a generally contaminated area. MW-5D is over 1300 ft from PGT, and small changes or spatial variability in strike direction, or pinch out of individual conductive units, could shift the flowpath from PGT to one side or the other of MW-5D.

Finally, a portion of the shallow contamination on the north side of PGT may descend into bedrock and initially migrate generally along-strike to the northeast but pass to the north of MW-5D. Over the horizontal distance from PGT to MW-5D both downdip and cross-aquitard migration, intensified historically by MTHD pumpage, may shift the flowpath from PGT to an alignment running north of MW-5D. Then further to the northeast within MTHD the east-northeasterly hydraulic gradient (Fig. 3.2) and historical Cleveland Cir. pumpage—which both intensify as one approaches the Millstone River—may draw the plume to Cleveland Circle.

In summary, limited water quality data south of MTHD (one well) does not resolve the southeastern boundary of the TCE plume. Therefore in Figure 3.5 I indicate this boundary as a dashed line.

Finally, as noted above, the northern extent of the bedrock plume to Sycamore Rd. may be attributable to shallow flow as shown in Figures 3.4 and 3.5 and/or to cross-strike bedrock flow.

The TCE plume shown in Figure 3.5 is consistent with a single source at PGT. Shepherd claims that an additional source exists at northern MTSP, Polycel and/or PCR and draws two separate plumes. He apparently believes that MTSP, Polycel and/or PCR are responsible for the entire MTHD TCE plume. I address the "entirety" contention in paragraph (2) below. First, however, I review the evidence concerning whether any MTSP, PCR or Polycel plume exists which contributes significant TCE to MTHD.

If an MSTP, PCR or Polycel plume is solely or principally responsible for contamination at MTHD, then that plume must also be responsible for the contamination detected at intervening monitoring well MW-4D. Therefore identification of a major MSTP, PCR or Polycel plume is essentially equivalent to linking one or more of these properties to contamination at MW-4D.

Monitoring well MW-4D, 120 ft east of the northeast corner of the former Polycel building, has been the most highly contaminated bedrock well at the Sites, containing up to 760 ug/l TCE, 37 ug/l DCE, 17 ug/l PCE, 24 ug/l 1,1-dichloroethane (11DCA), and 23 ug/l Freon 113. Although nominally a bedrock well, it is open from 20-150 ft bgs which includes the water table (MW-4S has always been dry and is open down to an elevation 0.5 ft above the top of the MW-4D open interval). Vertical profile sampling at MW-4D found very similar TCE concentrations from 20 to 140 ft bgs (CDM 1993).

I have discussed evidence concerning releases at MTSP, Polycel and PCR in Section 3.1, and examine additional issues here.

• *MTSP*. MTSP is a very unlikely source of the observed TCE at MW-4D, Polycel, or PCR due to the westerly location of the septic fields at MTSP[48], the nearly TCE-free water quality at MW-18, and the timing and predominance of PCE in postulated wastes disposed at MTSP (PCE from cleaners after 1989)[49]. Moreover, (if the chronology is correct) the installation date of the MTSP NW septic field itself is too recent to explain detected TCE in the early samples at MTHD.

• *PCR*. Due to its northerly location relative to MW-4D and due to northwestern shallow ground-water flow at the facility {May 2000, Fig. 3.4} , PCR is a very unlikely source of the contamination observed at MW-4D. It is not even clear that the along-strike component of bedrock ground water flow is toward the northeast beneath PCR, rather than toward the southwest (Section 3.2). Furthermore, the existing and new soil and water quality data from PCR does not demonstrate a release of TCE at the facility (Sect. 3.1.2). The low, consistent concentration of dissolved TCE—and a similar slightly less concentrated pattern of dissolved PCE—in the shallow ground water at PCR is more suggestive of an off-property source for these compounds than of a disposal location at PCR.

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[48] Figure 3-1 and {May 2000, Fig. 3.4} imply that shallow ground-water flow would not carry ground water from the MTSP NW septic field to well PCR-P2.
[49] PCE, TCA, 11DCA, and 11DCE were detected at wells PCR-P1, PCR-P2 and Polycel prior to 1989.

- *Polycel.* As discussed in Section 3.1, little is known of activities and potential releases at Polycel. One cannot rule out Polycel as a TCE source to MW-4D, but supporting evidence consists of only a single detection of a low concentration of TCE in a septic tank. None of the seven soil sampling locations at Polycel detected any TCE.

- In summary, PCR and MTSP are unlikely sources of the TCE observed at MW-4D or, therefore, of the TCE at MTHD. Field data do not conclusively eliminate Polycel as a source of observed MW-4D contamination, but supporting evidence also is lacking.

- On the other hand, the observed TCE at MTHD is explicable without postulating extra sources of TCE beyond PGT. To conclude that releases at PGT contaminated MW-4D, one must accept that ground water from PGT migrates northward by a combination of shallow flow, downdip flow and cross-strike flow. As discussed with respect to MW-17 and TW-2 above, this is a reasonable claim. And if flow proceeds this far, it is certainly reasonable to infer its continuance through the contaminated Polycel, PCR-P1, PCR-P2, P-21S, 29002-40 to 29002-43, 29003-13 to 29003-15, IW-1, and TW-1 wells, as well as through central MTHD to the northeast. This is essentially the single-source plume scenario of the RI (WCC 1988). It is consistent with available data concerning shallow and bedrock zone piezometric surfaces. Although it requires a mechanism of cross-strike flow, such a mechanism must exist per the argument of Section 3.3.

I emphasize that regardless of releases postulated at PCR and Polycel, there is evidence that PGT contributed TCE to the MTHD plume.

- Polycel and PCR are too far north to be the cause of contamination at MW-17 and TW-2. Under an assumption of PCR and Polycel as sources, the MW-17/TW-2 contamination still reflects a plume emanating from PGT. The PGT TCE in this scenario migrates from the MW-17/TW-2 vicinity along-strike through the southern portion of MTHD including the Cleveland Circle residences. As noted in Section 3.4.1, the plumes drawn by Shepherd omit the observed contamination at Cleveland Circle, and he does not address the issue.

3.5 TCE Migration from PGT to RHMW

Chirlin (2000) and this report (Figures 3-4, 3-5) indicate TCE migration from PGT to RHMW. Shepherd says nothing definitive concerning TCE migration from PGT to RHMW. However, he makes some statements which might later be used to support a claim that PGT's TCE is not entrained by RHMW. Therefore in this section I identify and respond to those statements.

There is general agreement that high concentrations of dissolved TCE existed within the shallow ground water at PGT. Shepherd also opines that ground water and dissolved TCE in the shallow zone descend into the bedrock aquifer at PGT by both natural and man-made (long open borehole) routes {vol. 2, pp. 28, A-12, A-21, A-23}. What remains to be discerned is Shepherd's opinion on the flowpath of bedrock ground water flow from beneath PGT.

- PGT's former consultant Dan Raviv, Chirlin (2000), this report, and others have determined that TCE in the bedrock ground water beneath at least a portion of PGT makes its way to RHMW. Raviv states unambiguously that "ground water in the deep aquifer zone beneath PGT is controlled by pumping at the RHMW and flows toward the RHMW...[and] is captured by the RHMW" [Raviv 1993a, para. 9]). Likewise Figures 3-2 and 3-5 of this report indicate direct migration of bedrock ground waters and dissolved TCE from a portion of PGT to RHMW. The expert report from defendants and third party plaintiffs FDI and Hilton Reality, et al. also concludes that "PGT is a major source of TCE contamination to the RHMW" (Environ, March 2000, pg. 14).

- One of Shepherd's bedrock piezometric diagrams, {vol. 2, Figure A-6}, indicates a potential gradient for bedrock flow from PGT to RHMW. Furthermore, if Shepherd had appropriately incorporated a cone of depression around RHMW in his diagrams, both of his diagrams {vol. 2, Figs. A-6 and A-7} would have implied a greatly intensified potential for flow from PGT to RHMW.

Shepherd {vol. 2, pg. 28} states that "because the groundwater divide in the deeper hydrostratgraphic unit is north of PGT, flow will be directed to the south-southeast in the deeper unit. This combination of bedrock structure trending to the northeast and the hydraulic gradient trending to the southeast results in a net resultant flow of groundwater to the east (Appendix A)". This statement might be used to claim that TCE within the bedrock beneath PGT migrates to the east rather than toward RHMW.

Shepherd's statement apparently claims that bedrock flow will move in a cross-strike direction (east) due to a different regional[50] cross-strike potential gradient (toward the south-southeast). This is incorrect, and his Appendix A provides no clarification of his reasoning.

- Based on topography and the distribution of streams it is likely that the unpumped regional gradient in bedrock beneath PGT is approximately toward the northeast, and not toward the SSE. Therefore if bedrock ground waters beneath PGT respond to a gradient toward the SSE as claimed by Shepherd, then they must be responding to pumping at RHMW (which is located to the SSE of PGT). Then the hydraulic gradient must be a consequence of hydraulic connectivity from RHMW to PGT, and flow from PGT is to RHMW and not in some intermediate cross-strike direction.

Furthermore, even if the regional gradient absent RHMW pumping is toward the SSE beneath PGT, its magnitude likely is dwarfed by the effect of pumping at RHMW at least beneath a portion of PGT.

Finally, prior to 1977 or 1982 when RHMW pumpage was 52% higher than during the Sites investigations, the gradient and consequent entrainment of PGT bedrock ground water by RHMW was intensified.

Shepherd {vol. 2, Sect. A. 2.1.4} claims that observed water level responses at PGT to RHMW pumpage are too small to reflect migration of water from PGT to RHMW. He

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[50] Shepherd claims that the south-southeast component of the gradient is driven by the location of the bedrock ground-water divide {vol. 2, pg. 28}, and that the divide placement is a consequence of regional features such as streambed distribution {vol. 2, pp. A-9 to A-10}.

attributes the observed cyclical drawdown in well PGT-P1 to a "pressure response" to RHMW pumping and states that "flow from these wells [e.g., MW-15D and PGT-P1] to the pumping well [RHMW] is improbable due to the presence of aquitard/confining layers and the anisotropic flow of groundwater along strike" {vol. 2, pg. A-7}.

- Shepherd offers no evidence that bedrock ground water fails to migrate from PGT to RHMW. He simply states a qualitative, unsupported opinion that the magnitude of the water level oscillations in PGT-P1 are too small to reflect flow to RHMW. In fact there are ongoing cyclical responses to RHMW at all three PGT bedrock wells PGT-P1, MW-7D, and MW-7DD. These reveal a hydraulic connection between RHMW and the shallow bedrock at PGT (see also Chirlin 2000, Sect. 4.2.4). Pumpage of RHMW creates both a net drawdown due to the average effect of the twice-daily pumping cycle at RHMW (Shepherd's "pressure response") and a damped component of drawdown in the bedrock due to depletion of slower draining components of the aquifer system. These include the shallow zone and lower permeability fractures; and these likely take days to fully recover.[51] The pump test responses demonstrate that bedrock at PGT is hydraulically connected to RHMW. Therefore it is expected that bedrock water level beneath PGT is chronically depressed by the long-term pumpage of RHMW and it is likely that PGT lies within the zone of capture of RHMW.

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[51] Evidence of this component is available from water levels collected on December 13, 1986 fourteen hours after cessation of RHMW pumping (WCC 1988, Table 5-1). At that time there were still several feet of residual drawdown at RHMW (RHMW was then 101.84 ft NGVD whereas more easterly—downgradient—MW-9D was 105.34 ft NGVD).

4. REFERENCES

(Note: In the interest of full disclosure this list also includes documents obtained and/or referred to subsequent to Chirlin 2000 but not cited in the text of this rebuttal report).

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FIGURES
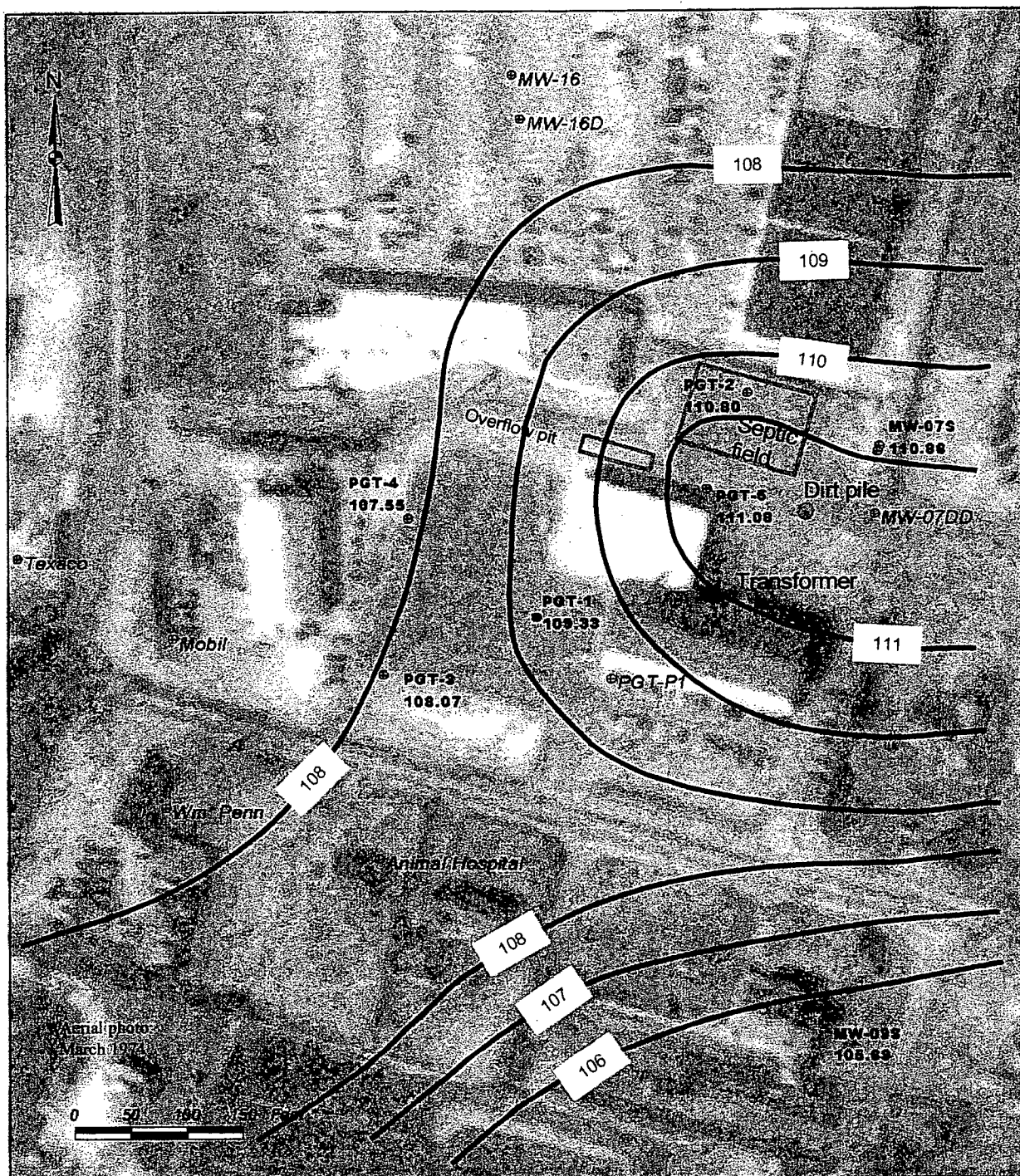
Contours reflect posted data, topography, and RHMW-induced drawdown. Contours are less certain outside of water elevation control points. (See text).

— 108 — Ground-water elevation (ft NGVD)

Elevation at PGT-5 is approximated (see text)

Gas station wells locations are approximate

Shallow water elevation data for 8/11/93 from DRAI (Sept. 1993, Table IV)

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Figure 2-1 Shallow piezometric surface in the PGT vicinity

Contours reflect posted data, topography, and RHMW-induced drawdown. Contours are less certain outside of water elevation control points. (See text).

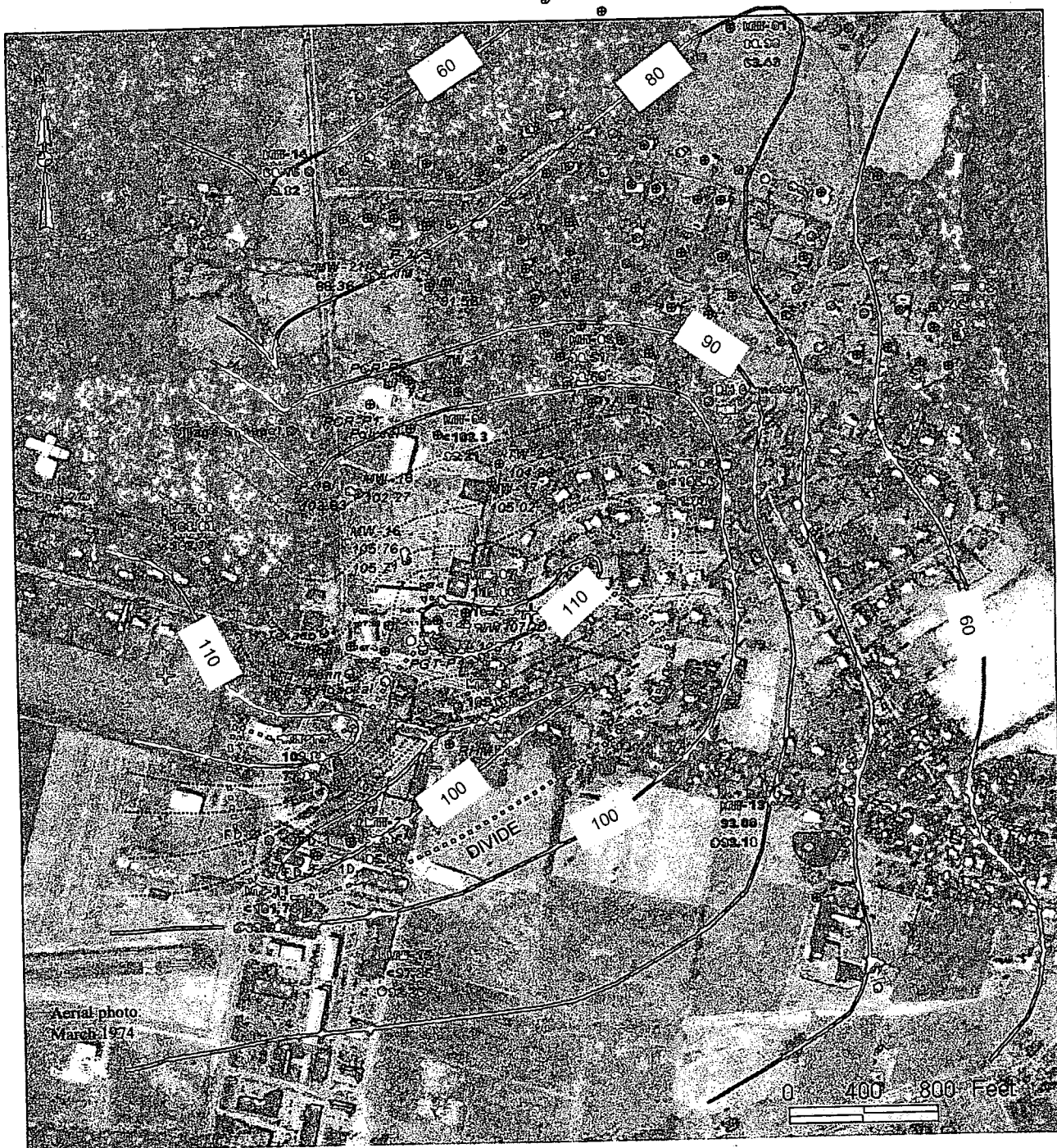Shallow (upper value) and deep water elevation data shown as bold values; italicized wells are deep only.

Water elevation data for 8/11/93 from DRAI (Sept. 1993, Table IV)
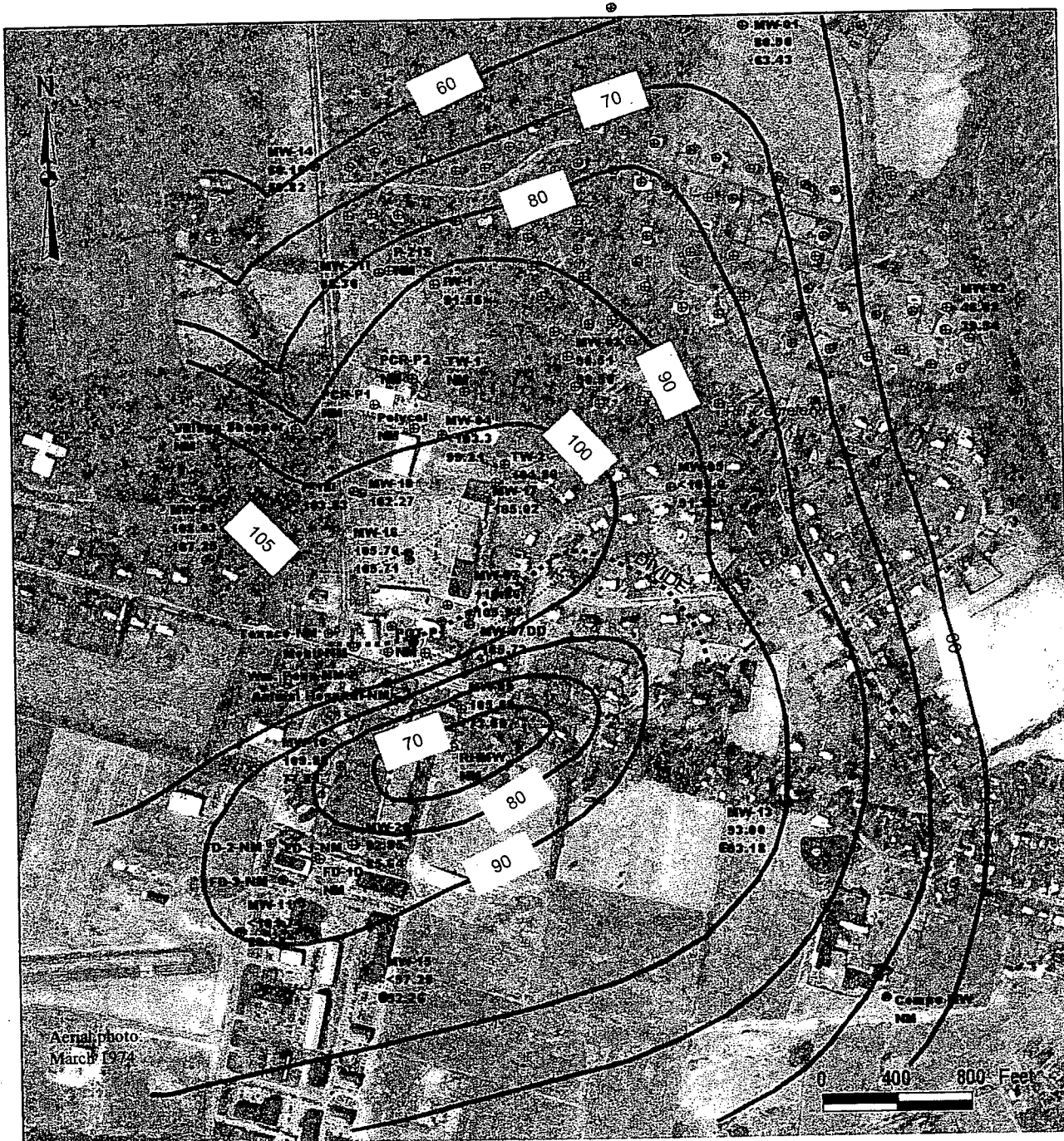
— 108 — Ground-water elevation (ft NGVD)

NM = not measured

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Figure 3-1 Regional shallow piezometric surface

Contours reflect posted data, topography, and RHMW-induced drawdown. Contours are less certain outside of water elevation control points. (See text)

Shallow (upper value) and deep water elevation data shown as bold values; italicized wells are shallow only.

Divide placement is not well-defined.

Water elevation data for 8/11/93 from DRAI (Sept. 1993, Table IV)

——— 108 ——— Ground-water elevation (ft NGVD)

NM = not measured

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Figure 3-2 Regional bedrock piezometric surface

Surface topography from USGS Rocky Hill
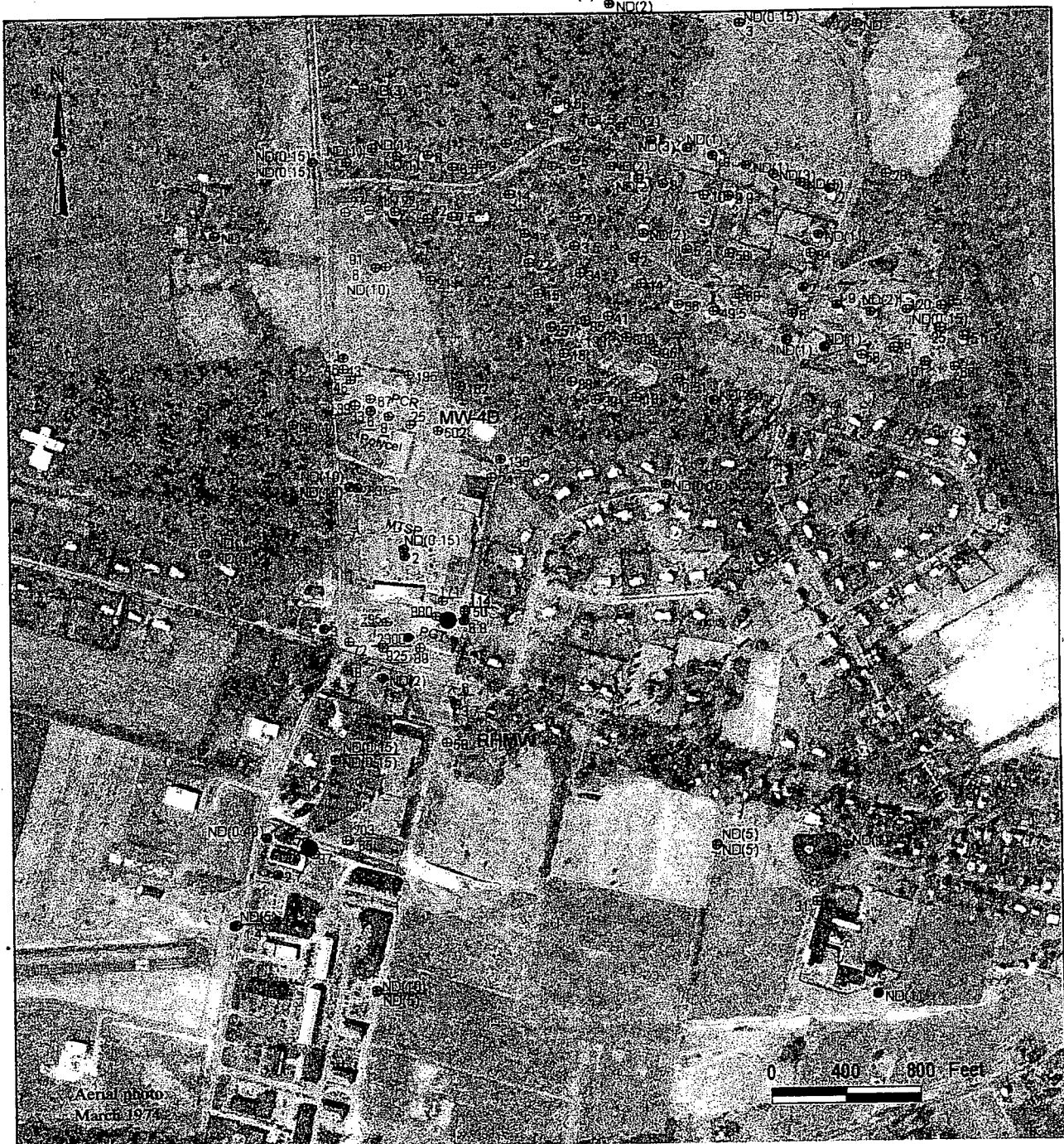7.5-minute quadrangle, 1954

Geologic strata from Parker & Houghton
(1990)

Upstream (southern) extent and
intermittence of unnamed tributary are
uncertain.

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Figure 3-3 Regional surface topography and
geologic strata

Figure 3-4 Shallow TCE Distribution

TCE Median (ug/l)
- ND
- 0.1 -10
- 10-100
- 100-1000
- >1000

Area with shallow ground-water contamination by TCE
(sources at PGT, FDI)

● Known areas of TCE release (approximate)

Shallow water quality data is available only at underlined values. All other values are bedrock water quality data

For discussion of the extent of shallow plumes, see text.

Continued migration is shown in Figure 3-5.

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TCE Median (ug/l)
- ⊕ ND
- ⊕ 0.1 -10
- ⊕ 10-100
- ⊕ 100-1000
- ● >1000

Area with bedrock ground-water contamination by TCE
(sources at PGT, FDI)

Poorly-defined boundary of TCE plume (see text)

● Known areas of TCE release (approximate)

Shallow water quality data also are shown
(underlined values in Figure 3.4)

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Figure 3-5 Bedrock TCE Distribution